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THE GEOLOGY OF TEXAS

Volume II

Structural and Economic Geology

By

E. H. SELLARDS AND C. L. BAKER

Including Chapters by Members of the United States Geological Survey and Others

Bureau of Economic Geology

E. H. Sellards, Director

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

CONTENTS

Part 1

Part 3

ILLUSTRATIONS

FIGURES

PLATES

PREFACE

Volume I of The Geology of Texas, University of Texas Bulletin 3232, issued July, 1933, relates to stratigraphy. The present publication, Volume II of the series, is introductory to the structural and economic geology of Texas. Both structural and stratigraphic geology are very closely concerned with mineral resources. The rocks of the earth's crust form the storage reservoirs for the minerals and mineral products useful to man. Many of such reservoirs in the rocks are determined by structural conditions. The accumulation of oil and gas is dependent upon structural and stratigraphic conditions. Large sulphur deposits are found in the salt domes of the Gulf Coastal region. These domes likewise contain oil, gas, salt, gypsum, and anhydrite, as well as other minerals in smaller amounts. The deposits of the mercury minerals in Brewster County have been shown to be closely related to structural conditions. The underground water supply, so essential to the agricultural development of the country, is dependent upon stratigraphic and structural conditions favorable to accumulation. A knowledge of the stratigraphic and structural geology is, therefore, essential to a study of the economic geology and mineral resources.

The discussion of structure in this volume is necessarily confined to the major features, structural trends, and regional structural conditions. To go beyond these limits would unduly increase the size of the volume. Moreover, many details of structure have already been given in connection with the numerous papers on the oil fields of the state that have appeared in various publications, and additional structural details will be given in a subsequent volume in connection with the discussion of petroleum.

The part of the volume relating to economic geology includes an account of the mineral resources other than petroleum. The mineral resources of the state are so varied that it has been necessary to confine the treatment given here to a brief discussion of the various minerals and mineral products and to defer discussion of petroleum to a later volume.

For the volume as a whole, acknowledgment is made of indebtedness to many geologists who have given suggestions and constructive criticism. Several such acknowledgments are included in the text. Special acknowledgment is made for chapters on iron ores, quicksilver, silver, and potash, contributed to this volume by

the United States Geological Survey. Acknowledgments for the structural map of the state (Pl. I) are given on a subsequent page. The columnar section, as will be seen by consulting the legend on the map, is built up from various parts of the state, the full section not being found at any one locality. Under these conditions, variation in facies and in thickness cannot be expressed and the section applies in detail only to the locality indicated from which it is taken. Among those whose published or unpublished data have been incorporated in this section are the following: W. B. McCarter and P. H. O'Bannon, Sugarland oil field, Fort Bend County; L. P. Teas and C. R. Miller, Raccoon Bend oil field, Austin County; B. Coleman Renick, Yegua to Reklaw formations, Brazos County; F. B. Plummer and H. B. Stenzel, Carrizo to Seguin formations, Milam and Robertson counties; F. B. Plummer, Midway, Limestone County, and Pennsylvanian, Palo Pinto County; W. S. Adkins, Gulf Cretaceous, Rockwall and Dallas counties, and Jurassic of Malone Mountains, Hudspeth County; R. T. Hill, T. W. Vaughan, and Robert Cuyler, Comanche Cretaceous, Austin region; M. E. Roberts, Triassic of central Llano Estacado; Henry Rogatz, Permian, Carson and Hutchinson counties; E. F. Boehms, Upper Permian, Reagan County; Wallace Lee, Pennsylvanian, Young County; P. B. King, Devonian and Ordovician, Marathon region. This section has been made by C. E. McCarter. Valuable constructive criticism of the section has been given by H. B. Stenzel.

As in Volume I, the sources of information drawn upon are too numerous for full citation. Constant reference is made to the bibliography and subject index of Volume I, and footnote citation is given where practicable.

As indicated on the title page, this volume was initiated and a bulletin number in the series of The University of Texas publications assigned early in 1934. The printing of the volume, however, was not completed as shown on the first text page, until December, 1935. Engraving of the structural map, Plate I, cannot be completed until early in 1936. During the year 1936, the State of Texas celebrates the one-hundredth anniversary of independence from Mexico. This volume on the state's resources may therefore be designated as *A Texas Centennial Volume.*

E. H. SELLARDS, *Director,*
Bureau of Economic Geology.

November 14, 1935.

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Volume II

Structural and Economic Geology

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INCLUDING CHAPTERS CONTRIBUTED BY MEMBERS OF THE UNITED STATES GEOLOGICAL SURVEY AND OTHERS

Part 1

MAJOR STRUCTURAL FEATURES OF TEXAS EAST OF PECOS RIVER

E. H. SELLARDS

INTRODUCTION

The State of Texas, including approximately 265,000 square miles, presents a wide diversity of structural features. In viewing the structural history of this region as a whole, it is necessary to be able to visualize land and water relationships in the past, vastly different to those of the present time. For the great expanse of Paleozoic time we must recognize a land mass, known as Llanoria, which occupied much of the present Gulf Coastal Plain and from which sediments were carried westward through all or nearly all of Paleozoic time. Of special importance in its structural relations was a basin of deposition receiving chiefly clastic sediments lying at the west or northwest margin of this land mass. This trough, which received sediments, and the land mass, which supplied them, were the seat of extensive Paleozoic diastrophic movements. Farther to the west and northwest, in central Texas, was a large region which was often flooded in Paleozoic time. This region received a limited amount of clastic sediments, together with extensive calcareous sediments such as limestones and dolomites. This region was subjected to much less violent disturbance than was either the trough or the Llanoria land mass. It was, however, affected by

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Issued December, 1935.

localized uplifts and downwarps which may have been the reflex from much more violent disturbances to the east.

It is convenient to refer to the Coastal Plain region, containing the Paleozoic land mass, as the "hinterland" or "back land," to the trough of Paleozoic time, receiving clastic sediments, as the Llanoria geosyncline, and to the large area west or southwest of the depositional trough as the "foreland." These terms will be used in this sense.

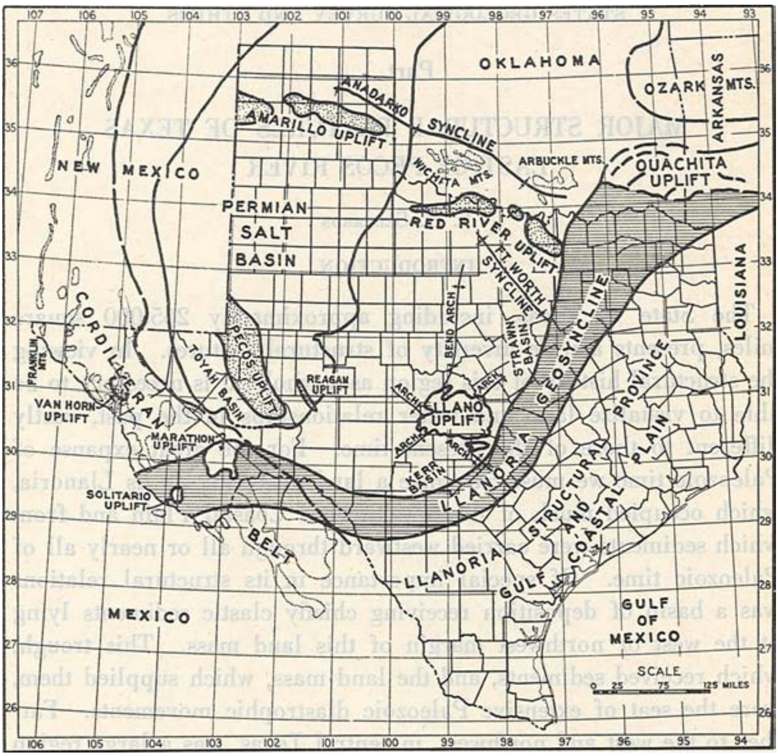

Fig. 1. Index map showing the location of some of the structural provinces and major structural features in Texas.

Early Mesozoic time revealed an emergent continent inherited from late Paleozoic time, but by the close of Mesozoic time a vastly different picture was presented. The "hinterland" of Paleozoic time and the trough which had been the Llanoria geosyncline were covered in Texas by Cretaceous sediments. The streams were reversed in direction and were now flowing gulfwards, and the present-day order with respect to land distribution had been in part established.

Aside from the formation of salt domes, the most outstanding change in Cenozoic time was the formation of the later systems of the great Cordilleran mountain belt which crossed Trans-Pecos Texas in a direction almost at right angles to the trend of the belt of major Paleozoic diastrophism. The diastrophism of this period in west Texas and elsewhere included, at different times, folding, thrusting, laccolithic intrusions, volcanic flow, and basin range block-faulting. From this orogeny was formed the Rocky Mountain system, not conspicuous in Texas but including high ranges in states to the north and in Mexico.

To present this varied structural history, representing so much of geologic time and such diversity of physical conditions, it is desirable to give, in the following pages, first an outline of the principal diastrophic movements and their time of occurrence, followed by a description of structural features and trends according to the more or less natural geographic and structural subdivisions of the state. The most important of these subdivisions, both structural and geographic, are indicated in the accompanying sketch maps, Figures 1, 3 and 15 (pp. 12, 32 and 138) and in Plates I and IV (in pocket).

PERIODS OF STRUCTURAL DEFORMATION AFFECTING THE TEXAS REGION

Each formation in its present attitude expresses the sum total result of all deformational movements of the immediate locality from the time the sediments were deposited until the present time. Conversely, each formation is essentially unaffected by whatever deformational movements may have occurred previous to its deposition. It will be helpful, therefore, to state something of the major structural changes occurring in the successive eras or periods. This outline of structural development will be briefly presented here, mention being made of the major deformational movements only and in the order in which they occurred. Subsequently, a more detailed account of the resulting structural features will be given. Deformational movements may express themselves in folding, thrusting, faulting, doming, or in mountain-making involving all of these, or may include the elevation and depression of areas continental in extent. Changes involving elevation and depression without pronounced folding or faulting are of very frequent occurrence in geologic time and are often difficult to detect, being recorded only in disconformities, overlaps, erosion surfaces, or changes in sediments. To detect such earth movements may be of the greatest importance since they may reflect and be coincident with much more violent diastrophism elsewhere. Overlap and disconformities in Texas in the foreland region of Paleozoic time may, for instance, reflect pronounced diastrophism in the hinterland which cannot otherwise be detected, since that region is now concealed by later deposits. These minor breaks in sedimentation, important as they may be, cannot be fully mentioned in this brief summary.

DEFORMATIONAL MOVEMENTS OF PRE-PALEOZOIC TIME

The pre-Paleozoic formations of Texas have been described in some detail in Volume I. The formations there mentioned are in the Llano, Van Horn, and El Paso regions. (See geologic map accompanying Volume I.) Although of limited extent in surface exposures, these formations afford a record of complicated deformational movements occurring previous to the deposition of the earliest overlying formations which are of Upper Cambrian age.

Structural features in the Llano region which antedate Upper Cambrian time include folds trending northwest-southeast and plunging southeast. The pre-Paleozoic sediments in this region were very extensively intruded in pre-Upper Cambrian time by igneous material, chiefly acidic in character, forming granite, although other more basic rocks are present. Extensive erosion occurred previous to Upper Cambrian time, truncating the folds and exposing the granites and other igneous rocks. All the pre-Cambrian rocks of this region are more or less altered and are at many localities foliated and schistose. The pre-Paleozoic formations of the Llano region are also for the most part highly tilted in contrast to the very mildly inclined overlying Paleozoic formations. (See structural map, Pl. I.)

According to Dr. H. B. Stenzel, who has made a special study of the structural conditions in this region, several periods of deformation are recognized in the pre-Cambrian of the Llano uplift. The following summary of these deformations has been prepared by him. The first recognizable deformation occurred before the intrusion of the granites. During that time the ancient sediments of the region were folded intensely, in many places in isoclinal arrangement. In the later stages of the folding, magma intruded along the bedding planes. This magma was drawn out along and forced into the bedding planes through the folding movement by the gliding and shearing of the various beds one over the other. The combined action of the magma and the stresses of folding metamorphosed the ancient sediments to schists, lime silicate schists and marbles and the magma itself solidified as gneiss. This possibly is the origin of the Packsaddle schists and the Valley Spring gneiss. Both formations were essentially in their present form before the granites intruded.

The second deformation is essentially the time of intrusion of the Town Mountain granite magma. During that time the folding continued but it was much more restricted than before. However, the folding movement exercised a very definite influence on the granites. First, it localized the granite magma in the spaces in which it solidified and where it is now exposed. Second, it made the granitic magma flow slowly from higher to lower pressures, producing the flow structure in the granite.

The third deformation is accompanied by intrusion of the Oatman granite magma. The tectonic movements of this time did not produce much if any further folding. Large fissuring seems to have been the chief type of deformation. Into these fissures the granite magma found its way and, on solidifying, formed elongate bodies arranged *en échelon*. These bodies are elongate along the strike of the surrounding schists and gneisses.

The fourth deformation is essentially the time of intrusion of the Sixmile granite magma. Very little is known of the structural position of these granites.

The last deformation is recognizable through the presence of felsite and porphyry dikes. The deformation produced fractures in various cross-cutting directions. The magma rose along these fractures and solidified in it forming dikes.

It is possible to regard these different deformations as one continuous series changing slowly from intense folding to fracturing as the intruded masses proceeded to cool and weld the rocks together slowly inhibiting folding and bending so that finally only fracturing was possible. This point of view is possible but perhaps not justified, because the time elapsed between the different intrusions was great; so great that the older intrusions were solidified sufficiently to break into fragments rather than to yield plastically before the next younger mass intruded. Therefore, it is probable that these deformations occurred in definite paroxysms separated by large time intervals.

Two pre-Paleozoic formations, or series, are recognized in the Van Horn region, the Carrizo Mountain and Millican. Thrust-faulting occurred probably in pre-Cambrian time by which the Carrizo Mountain formation was thrust northeast and in the vicinity of Eagle Flat station over the Millican formation. The supposed Cambrian sandstone, Van Horn formation, rests with angular unconformity on the Carrizo Mountain and Millican formations. Although modified in much later time, the steep dips of the Carrizo Mountain formation were chiefly developed during pre-Paleozoic time, as were also the alteration and schistosity in the rock. The Carrizo Mountain formation is older, has undergone more alteration, and has been subjected to more pronounced structural deformation than has the Millican formation. The Van Horn sandstone is now provisionally placed as Cambrian in age without, however, evidence from fossils. This formation, which is separated from both the Millican and Carrizo Mountain formations by an angular unconformity, may prove to be of pre-Cambrian rather than Cambrian age. It is separated, likewise, from the overlying Ordovician by an unconformity of slight angularity and thus affords evidence of a third period of deformation in this region previous to Ordovician time. The first of these deformations is post-Carrizo Mountain; the second, post-Millican; and the third, post-Van Horn in age.

The pre-Paleozoic of the Franklin Mountains in the El Paso region, in contrast to that of the Llano and Van Horn regions, suffered little, if any, deformation in pre-Paleozoic time. The Lanoria quartzite of this region and the overlying rhyolitic rocks lie essentially concordant with the overlying Paleozoic formations and present a westerly dip derived from pronounced faulting of relatively late geologic time. The sediments were, however, intruded by acidic igneous rock in pre-Paleozoic time and were largely altered to quartzite probably chiefly by circulating waters. Further information on the Van Horn and El Paso regions is given by Mr. Baker under the heading Trans-Pecos Texas.

DEFORMATIONAL MOVEMENTS OF PALEOZOIC TIME

Paleozoic time is believed to have been of much shorter duration than was the time of the accumulation of the pre-Paleozoic sediments. Consistent with this view is the fact that structural deformation in the pre-Paleozoic sediments is much more widespread and more intense than in the Paleozoic sediments. However, since the Paleozoic formations are now exposed over wide areas there is a better opportunity for observing the evidence of structural movements than in pre-Paleozoic strata. Those earth movements which are known to have strongly affected the Texas region are here given in order for each of the several Paleozoic periods.

Cambrian.—Lower and Middle Cambrian sediments are absent so far as known in Texas. Their absence probably indicates that the Texas region, or that part from which these sediments are known to be absent, stood relatively high in early Cambrian time. The parts of the state in which Lower and Middle Cambrian are believed to be absent include all the pronounced uplifts of the state where pre-Cambrian formations are brought to the surface or reached by the drill, as follows: Llano, Red River, Amarillo, and Pecos uplifts and the Franklin Mountains. The Van Horn region should probably be included although, as previously explained, there is doubt as to the age of the Van Horn sandstone. These uplifts, as will be seen from the map, Figure 1, page 12, are distributed through much of Texas west of the Gulf Coastal Plain. That early Cambrian is present in some part of the region between these uplifts is possible but, in the light of all available information, seems improbable. The indications are, therefore, that much of the Texas region, as was true also of much of the North American continent, was emergent during early Cambrian time. Lower and Middle Cambrian deposits were formed in the two great geosynclines of the continent, the Appalachian and Cordilleran, and may have accumulated also in some part of the Llanoria geosyncline in the Texas region but, if so, are now concealed by the overlying Cretaceous deposits. (See Vol. I, pp. 127–140.) No evidence exists by which to determine either that there were or were not diastrophic movements in the Texas region during this part of the Cambrian period. Obviously some of the intense folding in the pre-Cambrian formations, which is dated only as earlier than the overlying Upper Cambrian, may have taken place in Lower or Middle Cambrian.

Upper Cambrian time witnessed a great inundation of the interior of the North American continent. Localities in Texas where the Upper Cambrian sea is known to have transgressed across a land surface consisting in the main, if not entirely, of pre-Cambrian formations are the Red River and Llano uplifts and the Franklin Mountains of the El Paso region. Upper Cambrian is exposed also in the Marathon and Solitario uplifts, but its relation to older formations is there undetermined, the base of the Upper Cambrian not being exposed. The Upper Cambrian is probably present in much of the intervening area between these uplifts. In Volume I, page 68, is a map indicating the probable extent of the Upper Cambrian sea. The depression of continental extent which brought about this great inundation in Upper Cambrian time, affecting much of the interior of North America, was apparently gradual and progressive, although there were some fluctuations of level, or of sea connections, affecting the faunas. In the Llano region during and at the close of the Cambrian there occurred some slight shifting in elevation resulting in disconformities often difficult to detect except as revealed by the change in fauna. In the Van Horn uplift, however, an unconformity of slight angularity separates the supposed Cambrian, the Van Horn sandstone, from the overlying Ordovician (Vol. I, p. 63). In the Texas region, so far as known, no extensive mountain-making movement during or immediately following Cambrian attended the land depression or elevation.

Beginning in late Cambrian time and continuing through Mississippian and probably a part of Pennsylvanian time, the Paleozoic deposits in Texas appear under two strikingly different facies. Sediments prevailingly clastic accumulated in a geosyncline bordering Llanoria, the principal Paleozoic land mass of the Texas region (fig. 1, p. 12), while sediments in part clastic and in part organic or chemical accumulated over a broad foreland region somewhat remote from the land mass (Vol. I, pp. 21–23).

Ordovician.—The Lower Ordovician sea occupied much the same, or possibly a somewhat greater, area in Texas as did the Upper Cambrian sea. (See Vol. I, p. 81.) Disconformities and overlaps occur in the Lower Ordovician sediments of the Llano uplift, recognized chiefly by change in faunas, there being no evidence of pronounced diastrophic movements in the Texas region during Lower Ordovician time.

The sediments of the Ordovician of synclinal facies consisting mainly of clastic materials are to be seen exposed in the Marathon and Solitario uplifts; elsewhere in the Llanoria geosyncline in Texas they are known only from well cores and cuttings. The thickness of the Ordovician sediments of synclinal facies is known only in the Marathon uplift where they are about 2000 feet thick. The Marathon uplift, however, is located probably at the margin of the geosyncline, and the early Paleozoic deposits of that region are in a measure transitional to the foreland facies. Thicker earlier Paleozoic deposits may exist in this geosyncline, now concealed by the surface covering of Cretaceous formations. Diastrophic movements, likewise, probably occurred in Ordovician time in the hinterland region of Texas, now concealed by a Cretaceous covering. Such movements in Lower Ordovician are probably indicated by disconformities and overlaps in the Llano region. Evidence of diastrophism in late Ordovician time is found in the boulders of Cambrian limestone found in the Woods Hollow formation and in conglomerates at the base of the Maravillas formation in the Marathon region.

At no one locality in the state is the full section of foreland facies of the Ordovician to be seen. In the Llano region the Lower Ordovician only is present. Not only are Middle and Upper Ordovician absent from this region but Devonian and Silurian as well. The Ordovician present, according to Dake and Bridge, shows overlap of younger formations onto older. The exposures now to be seen overlap westward, indicating in the main progressive depression in the region of these exposures during Lower Ordovician time. Middle Ordovician, in the foreland region, is known only in Reagan and Crockett counties where it lies in the Permian basin at a depth of 7000 or 8000 feet. Its absence from the Llano uplift may be due to erosion. This explanation, however, will not hold for the Trans-Pecos Texas region where the Upper Ordovician is present and hence seemingly would have preserved the Middle Ordovician if it had been deposited. There is, therefore, some probability that Middle Ordovician was a time of mild uplift in the Texas region excluding the Middle Ordovician sea from much of central Texas. On the other hand, there is the possibility that Middle Ordovician and later pre-Carboniferous deposits were present over much of central Texas and were lost by erosion in pre-Pennsylvanian time. The presence of a thick Ordovician section in that part of the Llanoria geosyncline accessible to examination and the probable presence of both Silurian and Devonian in that syncline in central Texas lend support to the possibility of there having been Middle and Upper Ordovician deposits in central Texas, now lost by erosion. Regions most likely to have retained such deposits are the Strawn and Kerr basins, and the Fort Worth syncline, not yet fully explored for the older formations (fig. 1, p. 12). The Permian basin under the High Plains is likewise unexplored for these formations except on the Amarillo uplift, and there they are absent, having been removed, possibly, by pre-Upper Pennsylvanian erosion.

The Upper Ordovician, well developed in the synclinal facies in the Marathon and Solitario regions, is wanting so far as definitely known from all the foreland region except in the Van Horn uplift and the Franklin Mountains, where it is represented by the Montoya formation. Whether its absence in central Texas is due to lack of deposition or to removal by erosion is undetermined.

In summary it may be said that there is no evidence of pronounced folding or mountain-making in the Texas region during Ordovician time. On the other hand, there probably were fluctuations in land level affecting the deposition of the Lower Ordovician in the Llano uplift and apparently preventing deposition of sediments in the Van Horn and El Paso regions and in most of central Texas during Middle Ordovician time. In the Llanoria geosyncline deposition was much more nearly continuous, as indicated by the Ordovician section of the Marathon and Solitario regions. The clastic materials are believed to have been supplied largely, if not entirely, from the Llanoria land mass (Vol. I, fig. 10, p. 128) in which diastrophic movements may have occurred.

Silurian.—No mountain-making is known to have occurred in the Texas region during Silurian time. Silurian sediments are probably present in that part of the Llanoria geosyncline adjacent to the Ouachita region of Oklahoma but are absent, so far as known, in the Marathon and Solitario exposures. In foreland facies the Silurian is present only as the Fusselman formation in the El Paso and Van Horn regions. Elsewhere in Texas, deposits of this system, so far as known, are absent, having been either not deposited or, if deposited, removed by erosion previous to Carboniferous time. The Silurian period may, therefore, have been a time of extensive land emergence and of limited marine deposition in the Texas region.

Devonian.—Devonian sediments are present in the Marathon and Solitario exposures and probably generally in the Llanoria geosyncline consisting chiefly of novaculite and chert. In the El Paso and Van Horn regions are thin Devonian deposits, chiefly shales. Elsewhere in Texas the Devonian, so far as known, is wanting. It appears, therefore, that the Devonian period in the Texas region was either a time of extensive land emergence and non-deposition or that the sediments accumulated were removed by erosion previous to the deposition of the Mississippian and Pennsylvanian time. Mountain-making movements are not known to have occurred in Texas during this period, although further uplift following this period is probably indicated by the absence of early Mississippian sediments in the Marathon region. The novaculite of the Marathon and Solitario regions may be in part or possibly entirely of early Mississippian age.

Mississippian.—The Mississippian system is but sparingly represented in Texas. Early Mississippian, the Kinderhook series, has not been recognized in the state; the Osage group is represented by a thin limestone, the Chappel formation; and late Mississippian, the Chester group, is represented by the Barnett formation of north-central Texas and by the Helms formation (restricted) of the Diablo Plateau region. In the Llanoria geosyncline Mississippian formations may be present, although such strata have not been definitely identified. On Honey Creek, near White Ranch crossing, 8 miles west of Mason, the Chappel formation rests, according to Dake and Bridge, on Ellenburger of upper Roubidoux or Jefferson City age and at some other localities on Ellenburger of Cotter age. The Barnett formation rests at some localities on the Chappel formation and elsewhere directly upon Ellenburger. The slight development of the system, the absence of the Kinderhook series, and the erosional intervals previous to, between, and following the Osage and Chester groups, indicate a relatively emergent condition of much of the Texas region during Mississippian time. No mountain-making movements are definitely known in the Texas region in Mississippian time except possibly near the close of the period, as stated below.

The Barnett formation, consisting chiefly of clastic materials, may represent an outward or feather edge of the sediment resulting from an uplift in Mississippian time. However, the counterpart of the Barnett formation of the foreland region is not definitely known in the Llanoria geosyncline. Uplift and depression of regional extent during Mississippian time are indicated by fluctuating seas in central Texas.

Pennsylvanian.—During early Pennsylvanian time an extensive series of sediments accumulated as detrital wash from the Llanoria land mass. These sediments are now exposed in the Marathon and Solitario regions in Texas, the Tesnus and later formations, and in the Ouachita region of Oklahoma, the Stanley and Jackfork formations. The Oklahoma formations, the Stanley and Jackfork, have heretofore been regarded by some as possibly in part or wholly late Mississippian. However, invertebrate and plant fossils, recently obtained, have enabled Girty and David White to determine definitely that these formations are of early Pennsylvanian age.[1] In the Llanoria geosyncline connecting these exposures early Pennsylvanian sediments are probably present, although now concealed by Cretaceous. This great belt of clastic sediments, extending approximately 1000 miles, from near Little Rock, Arkansas, southwestward across Oklahoma and Texas and probably into Mexico, is evidence of rapid accumulation from an adjacent land mass. The great thickness of these early Pennsylvanian sediments in this geosyncline, contrasted with the sparsity or absence of Mississippian sediments, indicates an extensive uplift of the hinterland which occurred near the close of Mississippian or in early Pennsylvanian time. The quantity of sediments, 15,000 or 20,000 feet in the Ouachita region and 10,000 feet in the Marathon region, is probably to be explained only by successive uplifts or by progressive uplift and erosion of a great land mass.

The foreland facies of the early Pennsylvanian includes in central Texas the Bend group consisting of the Marble Falls and Smithwick formations. These sediments, in part clastic and in part organic, probably represent essentially continuous deposition with, however, some shifting of depositional conditions. Equivalent sediments, with little doubt, are present in the Llanoria geosyncline, although, owing to the rarity of fossils in the syncline, the exact equivalency

[1]White, David, Age of Jackfork and Stanley formations of Ouachita geosyncline, Arkansas and Oklahoma, as indicated by plants: Bull. Amer. Assoc. Petr. Geol., vol. 18, pp. 1010-1017, 1934.

has not been determined. In the Llano uplift the Marble Falls formation of the Bend group rests at some localities on Mississippian and elsewhere upon various units of the Ellenburger group down at least to the Roubidoux, indicating erosion and shifting of sea level in this region between the latest Mississippian and the earliest Pennsylvanian deposits now exposed in this uplift. The Barnett formation, so far as known, is absent from the Red River uplift indicating non-deposition or more probably erosion from the uplift previous to deposition of the Bend sediments.

Following the close of deposition of the Bend group extensive diastrophism occurred in the foreland region of Texas. At this time the Llano region was re-elevated and severely eroded. The erosion of this time is known to have removed the Smithwick formation allowing the Strawn to be deposited on the Marble Falls formation. At the northwest side of the Llano region in Menard County, the Bend, which probably was formerly present, and the Mississippian, which may have been present, were entirely removed so that Pennsylvanian of Canyon age there rests on Ordovician. Well records show that at some places in this region Canyon rests directly upon Cambrian, the Ellenburger limestone having been entirely removed in post-Bend time.

The Red River uplift, likewise, was re-elevated in post-Bend time. That this is true is proven by remnants of the Bend group which persist locally on this uplift and by the fact that the overlying Pennsylvanian rests with angular unconformity on all older formations of the uplift across which it overlaps.

Closely following the Bend epoch, extensive diastrophic movements occurred in the hinterland by which the Llanoria geosyncline was obliterated as a basin of deposition. It is not possible at the present time to correlate fully orogenic movements in the hinterland of Paleozoic time in the Texas region with corresponding movements in the foreland. Coincident with or directly following the uplift of the Llanoria geosyncline another basin was formed intermediate between the Red River and Llano uplifts and west of the Llanoria geosyncline. This basin, which has been referred to as the Strawn basin, was occupied by the Strawn sea. The sediments in the eastern part of the Strawn basin, now covered by Cretaceous, are not available for examination, except occasionally as secured in small amounts in well samples. However, farther to the west in Palo Pinto and Parker counties where the Strawn sediments are at the surface, the conglomerates contain rocks recognized as having been derived from the Paleozoic of the Llanoria geosyncline, thus showing that at that time the geosyncline had been uplifted and its sediments were then exposed to erosion.[2] It is probable that this diastrophism was not confined to a limited period, but was progressive through a long period of time, and the earliest Strawn sediments of this basin may antedate the climax of the uplift. An approximate placing of this great period of orogeny would, however, seem to be early mid-Pennsylvanian. Viewing Paleozoic history up to Pennsylvanian time one cannot but infer that diastrophic movements, centering in the hinterland, occurred at successive intervals of time and progressed successively westward, the most pronounced effects in the foreland being seen in the uplifts and basins which were formed following Bend time. Pre-Pennsylvanian orogeny in the hinterland affected the foreland less violently but, nevertheless, with such results as to produce breaks and lapses in sedimentation recorded by more or less severe erosion.

In Trans-Pecos Texas the deformational periods are most advantageously studied in the Marathon region. This region is situated near the border of the Llanoria geosyncline. Its older deposits, particularly those of the southeastern part of the region, are of synclinal facies. On the other hand, the deposits at the northwest side of the region, particularly the later Pennsylvanian and Permian formations, partake of foreland facies. This border zone between these facies, therefore, affords an exceptional opportunity to determine the time of the great orogenic movements. In this region the orogenic movements appear to have culminated in late Pennsylvanian time. This is shown by the fact that the Gaptank sediments of Pennsylvanian age are involved in part if not as a whole. The deformation is best seen in the northwestern part of the mountains where early Paleozoic is thrust across greatly complicated Pennsylvanian strata of the Gaptank formation.[3] The strata exposed next above those involved in

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[2]Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 557–594, 1929.

Bay, Harry X, A study of certain Pennsylvanian conglomerates of Texas: Univ. Texas Bull. 3201, pp. 149–188, 1933.

[3]King, P. B., Geology of the Glass Mountains, Part I, Descriptive geology: Univ. Texas Bull. 3038, pp. 103–113, 1931.

the overthrust at this locality are of late Pennsylvanian or early Permian age. The uppermost part of the Gaptank formation, the Uddenites member, according to King, rests unconformably over strata warped by the latest phase of this orogenic movement. Highly tilted and folded strata of the lower and middle part of the Gaptank formation are exposed in the northeastern part of the basin. The uppermost strata of this formation, the Uddenites member, however, are nowhere seen to be highly folded and in the northeastern part of the area lie essentially conformable with the overlying Permian. The weight of evidence, therefore, is that the pronounced orogeny of this region culminated at or previous to the close of the Pennsylvanian. That some further diastrophism occurred in this region is shown by an angular unconformity between the Wolfcamp and Leonard-Hess formations and by a basal conglomerate overlying the Wolfcamp formation. A slight angularity occurs also between the Permian and Cretaceous formations.

Diastrophism quite certainly occurred also in this region earlier than the time of deposition of the Gaptank sediments, although the extent of such movements is less clearly defined. Evidence of diastrophism during Haymond time is found in arkoses, conglomerates, and erratics found at a horizon 400 or more feet below the top of this formation.[4] Still earlier uplift is indicated in the absence or limited development of Mississippian formations in the Marathon region. It seems reasonable to conclude that early Paleozoic orogeny, occurring in the hinterland, is reflected in the sediments accumulating in the geosynclinal trough.

In the foreland region of Trans-Pecos Texas several marked unconformities appear which, likewise, may be related to uplift in the hinterland, although such relationship is usually difficult to determine. The base of the Permian is exposed in the margins of the Diablo Plateau and there rests with angular unconformity on all older rocks present, overlapping all formations from Pennsylvanian to pre-Cambrian. Structurally the Permian is relatively uncomplicated while the Pennsylvanian and older rocks are more strongly

[4]King, P. B., Baker, C. L., and Sellards, E. H., Erratic boulders of large size in the west Texas Carboniferous (abst.): Bull. Geol. Soc. Amer., vol. 42, p. 200, 1931.

Sellards, E. H., Erratics in the Pennsylvanian of Texas: Univ. Texas Bull. 3101, pp. 9–18, 1931.

Baker, C. L., Erratics and arkoses in the Middle Pennsylvanian Haymond formation of the Marathon area, Trans-Pecos Texas: Jour. Geol., vol. 40, pp. 577–603, 1932.

folded. That this structural break coincides with the culmination of orogeny in the Marathon region appears probable.

Permian.—In north-central Texas no outstanding break in sedimentation separates the Pennsylvanian and Permian, and the exact limit of the two systems is in doubt. The most pronounced and widespread break that has been recognized in the Permian of north-central Texas is that which separates the Clear Fork and Double Mountain groups. The basal formation of the Double Mountain group, the San Angelo sandstone, locally conglomeratic, can be recognized more or less definitely from the Texas exposures northwards through Oklahoma and into Kansas.

A distinctly clastic facies of the Permian, the base of which is not exposed, is seen in the Chinati Mountains of Presidio County. (For location of Chinati and other mountains of Trans-Pecos Texas see fig. 15, p. 138.) The Permian formations of the Glass Mountains in the Marathon uplift present remarkable facies change both horizontally and vertically. Equally rapid changes in facies are seen in the Permian of the Delaware, Apache, and Guadalupe mountains and of the Diablo Plateau. The base of the Permian is not seen in the Delaware and adjoining mountains, but in the Diablo Plateau the basal Permian formation, the Wolfcamp equivalent, transgresses older formations down to pre-Cambrian, recording a great erosional unconformity.

The Bissett formation which is tentatively referred to the Permian, although it may be Triassic in age, rests unconformably on the Permian of the Glass Mountains. This formation, consisting of conglomerates, marls, and red beds, is of relatively local extent and is of nonmarine origin.

The extensive series of Permian sediments in the Permian basin affords evidence of fluctuating conditions terminating in the complete dessication of the basin accompanying uplift. The latest deposits of the basin, the Quartermaster formation, may represent wholly or in part wind and stream shifted sands.

DEFORMATIONAL MOVEMENTS OF MESOZOIC TIME

Paleozoic time closed with much of the continental areas emergent, and this condition continued through the early Mesozoic. However, a late Jurassic sea invaded Texas, to be followed by the great submergence of Cretaceous time. These changes in elevation were of continental areas and so far as known were not accompanied by orogenic movements in the Texas area, except the Laramide orogeny, which began near the close of Mesozoic time. The Sierra Madera Mountain, a pronounced local uplift in Pecos County, with little doubt, in its earliest form, antedates the Cretaceous of that locality, but whether the initial uplift occurred in late Permian, Triassic, Jurassic, or early Cretaceous time is undetermined.

Triassic.—The Triassic system is represented in Texas, so far as known, by nonmarine deposits only. The entire period, so far as the available record indicates, was one of continental uplift in the Texas region. The continental sediments that were accumulated and preserved lie in the Permian basin region and represent filling chiefly by stream wash from surrounding higher lands into that basin.

Jurassic.—Jurassic sediments are known in Texas only in the Malone Mountains and represent the latter part of the period, passing without obvious break into Lower Cretaceous. No records are found of orogenic movements in the Texas region in Triassic and Jurassic time. It is, of course, possible that such movements occurred without leaving evidence that has been as yet detected.

Cretaceous.—The Cretaceous period witnessed one of the greatest inundations of the continents of geologic time. In the Texas region the incursions of the sea across the land, beginning in the Malone Mountain region and possibly also in the Gulf Coastal Plain, in Jurassic time, continued until much, if not all, of the state as well as a great part of the interior of the continent was submerged. Somewhat pronounced breaks in sedimentation occurred, such as that which separates the Comanche and Gulf series. Other unconformities are recorded, and doubtless many exist which have not been detected. Viewed as a whole, however, the Cretaceous period records a subsidence of great magnitude which was in the main progressive until much of the continent was submerged and was then regressive by stages of retreat and advance until the continent at the close of the period was again emergent. These great changes of elevation were continental in scope, and localized mountain-making seems not to have been prominent in the Texas region during Cretaceous time except near the close of the period when the Laramide movements of the Rocky Mountain region were initiated. During a part of Cretaceous time, however, volcanoes, some of which probably were submarine, were active in the southwestern part of the inner Gulf

Summary of major diastrophic movements known in the Texas region including estimate of percentage submergence of the land area in successive periods.

Series or System	Conditions of Deposition	Estimated Submergence in Texas	Region of State to which Reference Is Made
Pleistocene	Marine and stream deposits	2% or less	Gulf margin.
Pliocene	Marine and continental	4% or less	Gulf margin.
Miocene	Marine and continental	6% or less	Gulf margin.
Oligocene	Marine and continental	8% or less	Gulf margin.
Eocene	Marine and continental; fluctuating conditions	35% or more	Large part of Gulf Coastal Plain submerged.
Upper Cretaceous (Gulf series)	Largely marine clays, shale, marls, chalk, and limestones	50% or more	Entire Coastal Plain and parts of west Texas submerged.
Lower Cretaceous (Comanche series)	Largely marine shales, marls, and limestones	100% (in Washita stage)	Progressive submergence probably of entire state.
Upper Jurassic	Marls and limestones	1% more or less	Known submergence in Malone Mountains only; Coastal Plain indt.; may have been partly submerged.
Lower Jurassic	No deposits known	0% (?)	Coastal Plain region indt.
Triassic	Continental	0% (?)	Coastal Plain region indt.
Permian	Sandstones, shales, limestones, dolomites, red beds, and salt; basin seas undergoing dessication	60%	Central and Trans-Pecos and Panhandle; Coastal Plains region indt.
Late Pennsylvanian	Sandstones, shales, limestones, red beds; shallow, fluctuating seas in central Texas	70%	Central and Trans-Pecos and Panhandle; Coastal Plains region indt.
Mid-Pennsylvanian	Sandstones, shales, and limestones; transgressing seas in central Texas	40% or more	Central and Trans-Pecos; Coastal Plains region indt.
Early Pennsylvanian	Limestones and shales, clastics in Llanoria geosyncline; shallow, clear seas in central Texas.	30% or more	Central and Trans-Pecos; Coastal Plains region indt.
Late Mississippian (Chester)	Shales and limestones; shallow, mostly clear, seas	20% or more	Central and El Paso-Van Horn; Coastal Plain region indt.
Mid-Mississippian (Osage)	Limestones; shallow seas probably of limited area	10% or more	Central; Coastal Plain region indt.
Early Mississippian	Not known; presumably lowlands	0% (?)	Coastal Plain region indt.
Upper and Mid-Devonian	Novaculite and shales; local submergence elsewhere presumably lowlands	5% or more	Trans-Pecos; Coastal Plain region indt.
Late Silurian	Not known; presumably lowlands	0% (?)	Coastal Plain region indt.
Mid-Silurian	Limestones; local submergence elsewhere presumably lowlands	3% or more	El Paso and Van Horn; Coastal Plains region indt.
Early Silurian	Not known; presumably lowlands	0% (?)	Llanoria geosyncline and Coastal Plains region indt.
Late Ordovician	Cherts, limestones, and shales; west Texas submerged, elsewhere presumably lowlands	5% or more	Trans-Pecos; Coastal Plain region indt.
Mid-Ordovician	Shales and some limestone; partial submergence, elsewhere presumably lowlands	2% or more	Marathon and south Permian basin; Coastal Plain region indt.
Early Ordovician	Limestones, dolomites and shales; extensive submergence; fluctuating, shallow seas	50% or more	Central and Trans-Pecos; may have extended under High Plains region; Coastal Plain region indt.
Late Cambrian	Sandstones, limestones, and shales; extensive submergence; fluctuating, shallow seas	50% or more	Central and Trans-Pecos; may have extended under High Plains region; Coastal Plain region indt.
Mid and early Cambrian	Not known; presumably extensive lands	0% (?)	Llanoria geosyncline and Coastal Plains region indt.
Pre-Cambrian not subdivided	Largely clastics with some limestone; intruded and extruded igneous rocks.	Indt.	Largely covered and indt.; extensive orogeny of two or more periods.

34. General emergent condition with no more than minor flooding of coastal margin of state in Pleistocene time.

33. Cordilleran orogeny. Extensive block-faulting in west Texas; possibly Balcones and associated faulting in Coastal Plain; possibly indicated by conglomerates of Goliad formation.

32. Submergence of coastal margin in late Tertiary time.

31. Uplift in Tertiary time sufficient to rejuvenate streams in central Texas resulting in deposition of Oakville and Lagarto formations containing reworked Cretaceous shells.

30. Submergence of Coastal Plain in early Tertiary Eocene time.

29. Laramide orogeny at or soon after close of the Cretaceous. Extensive mountain making in western United States; less intense in Texas.

28. Upper Cretaceous submergence.

27. Uplift at the close of the Comanche Cretaceous marked by extensive erosion in the Sabine uplift and lesser erosion in central Texas.

26. Late Jurassic-Lower Cretaceous submergence.

25. Emergent condition of Triassic-Jurassic time.

24. Permian submergence.

23. Minor orogeny, uplift, or fluctuations in level, producing conglomerates at the base of the Hess formation in the Glass Mountains region and possibly the conglomerates of the San Angelo formation in central Texas.

22. Early Permian submergence.

21. Great orogeny in the Marathon region near the close of Pennsylvanian time accompanied by extensive overthrusting.

20. Later Pennsylvanian submergence.

19. Uplift occurring within Pennsylvanian time obliterating the Llanoria geosyncline and affecting the Llano, Red River, and other regions.

18. Early Pennsylvanian Bend submergence.

17. Assumed great orogeny in the Llanoria region at or near the close of Mississippian time, the evidence for which is a thick accumulation of early Pennsylvanian, chiefly clastic sediments.

16. Submergence in Llano and Diablo regions in Chester time.

15. Assumed slightly emergent condition between Osage and Chester times.

14. Limited submergence in north-central Texas in Mississippian Osage time.

13. Assumed emergent condition of early Mississippian time.

12. Submergence of later Devonian time in Trans-Pecos Texas.

11. Assumed emergent condition of Upper Silurian and Lower Devonian time.

10. Submergence of mid-Silurian time in the Diablo Plateau region.

9. Assumed emergent condition during Lower Silurian time.

8. Submergence of Upper Ordovician time in Trans-Pecos Texas.

7. Assumed orogeny in the hinterland of the Marathon region accounting for Cambrian boulders in the Woods Hollow formation and for an unconformity at the base of the Maravillas formation.

6. Submergence of Middle Ordovician time in Marathon and southern Permian basin regions.

5. Assumed partial emergence at close of Lower Ordovician time.

4. Submergence of early Ordovician time.

3. Slight emergence at close of Cambrian time.

2. Submergence of Upper Cambrian time. Uplift in the Van Horn region produced a slight angularity. Dating of this uplift in doubt, probably post-Cambrian but possibly somewhat earlier.

1. Diastrophism of two or more periods affecting pre-Cambrian formations.

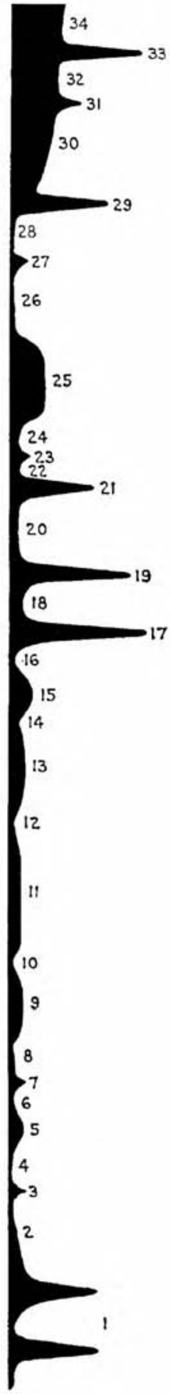

Fig. 2. Graphic representation of submergence and emergence of land in the Texas region.

Coastal region from Williamson County northwestward to Kinney County or beyond. (See geologic map of Vol. I.) Of the many igneous masses, now more or less altered, some afford evidence of having been exposed to erosion during Eagle Ford time. Some were extruded following Austin time, and some probably were intruded or extruded in late Cretaceous time. Some altered rock, apparently of these flows, is found in the Edwards formation. These igneous masses, whether intrusive or extrusive, affected structural conditions only very locally.

The changes in land elevation occurring in Cretaceous time were accompanied by warping of the land surface resulting in basins of deposition such as the Rio Grande embayment and the northeast Texas embayment. That downwarping in these areas, which may have begun as early as Jurassic time, continued through Cretaceous time is shown by the great thickness of Lower and Upper Cretaceous sediments that accumulated in these embayments in contrast to the thinner deposits of the intermediate positive region. The Sabine uplift, likewise, was elevated within Cretaceous time as shown by the great erosional unconformity between Lower and Upper Cretaceous on that uplift.

Viewing Mesozoic time as a whole, it will be seen that the outstanding structural changes were those associated with the tilting gulfwards of the Texas region and more particularly the foundering of the great Llanoria land mass. Through all of Paleozoic time and probably into the Mesozoic, drainage in central Texas was westward or northward from the Llanoria land mass. The drainage direction could have been partly reversed as early as Permian or Triassic and doubtless was largely reversed before the close of Jurassic and was completely reversed by the beginning of the Cretaceous period. This great change in physical conditions in the Texas region, resulting in a lowering of the ancient land mass of the Coastal Plains, Llanoria, far below sea level was, so far as known, unaccompanied by orogeny in the Gulf Coastal Plain other than vulcanism.

Under these conditions it seems probable that large normal faulting would result. It seems reasonable also that the hinge on which such relative change of position would take place would be in the geosyncline of clastic sediments which separated the two areas.

These sediments, as already stated, had probably been much crumpled, folded, and thrust in Pennsylvanian time. These considerations lead to the conclusion that the Balcones line of faulting may have originated as early as Mesozoic time. However, as depression continued through Cenozoic time, this and other lines of faulting underwent progressively enlarged development. The fact that the Balcones zone lies within and coincides with the Llanoria geosyncline has previously been stated.[5]

DEFORMATIONAL MOVEMENTS OF CENOZOIC TIME

The great deformational movements of Cenozoic time were those that resulted in the formation of the Rocky Mountains. The principal orogeny of the Rocky Mountain folding was probably in Miocene and later time. The extensive block-faulting of the Cordilleran region may be even later than Miocene. Extensive lava flows and intruded igneous masses occurred in this region in Cenozoic time. The Cordilleran belt and the associated basin range structural features cross Trans-Pecos Texas and continue into Mexico. The salt domes of the Gulf Coastal Plain formed progressively through the Cenozoic.

A broad depression through northeast Texas, known as the northeast Texas syncline, probably originated in Cretaceous time or earlier and was continued through Eocene time. The Rio Grande embayment, likewise, as a structural feature continued through Cretaceous and Cenozoic time.

In the Gulf Coastal Plain of Texas the Gulf shore line alternately retreated and advanced in Cenozoic time. As a whole, retreat of the shore line has exceeded advance so that the shore line has receded and the land area has increased. This retreat of the shore line may be due in part to the filling in of many thousand feet of Cenozoic sediments or to increased deepening of the gulf and ocean basins, accompanied by slight uplift of the non-Coastal Plain region of Texas.

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[5]Sellards, E. H., Oil fields in igneous rocks in Coastal Plain of Texas: Bull. Amer. Assoc. Petr. Geol., vol. 16, p. 745, 1932.

DESCRIPTION OF STRUCTURAL FEATURES BY GEOGRAPHIC PROVINCES

For convenience of treatment the structural features of Texas are described under the following geographic provinces of the state: Gulf Coastal Plain, Central Texas, High Plains, and Trans-Pecos Texas. Of these provinces or subdivisions the structural features of the first three are described in Part 1 of this volume. The structural features of Trans-Pecos Texas are described by Mr. C. L. Baker in Part 2 of this volume. The location of these subdivisions of the state is shown in the accompanying sketch map. Although convenient for descriptive purposes, it is not assumed that these subdivisions of the state are structural units. On the contrary, each subdivision presents within itself a wide diversity of structural con-

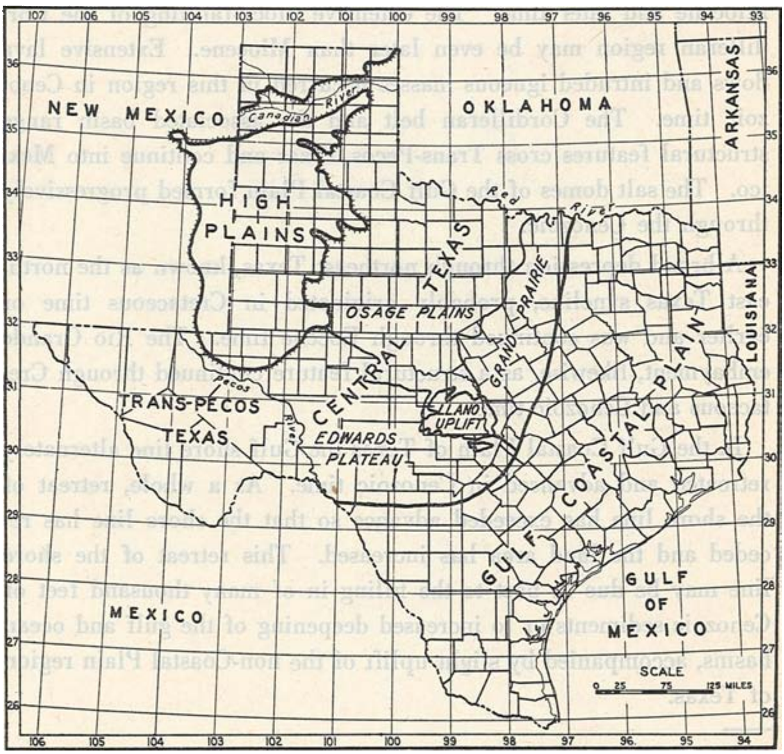

Fig. 3. Sketch map showing geographic provinces in Texas referred to in the text. For geographic subdivisions in Trans-Pecos Texas see Figure 15, page 138.

ditions. Some of the structural features as the Red River uplift, Bend arch, Toyah basin, Pecos uplift, and the great Permian basin transgress the limits of any one geographic province. For location of these structural features see Figure 1, page 12.

TEXAS GULF COASTAL PLAIN

The Texas Gulf Coastal Plain is part of a great plain bordering the Atlantic Ocean and the Gulf of Mexico extending from the southern New England states to the Yucatan peninsula in southern Mexico or beyond. This great Coastal Plain is, in fact, a partially submerged, partially emerged, continental shelf. During a part of Cretaceous time the shelf was entirely submerged. During Cenozoic time the amount of submergence has varied. There has also been warping of the plain. Thus, at the present time the entire shelf opposite the northern New England states is submerged, and Cretaceous and early Cenozoic deposits, if formed there, are not now exposed. Florida, on the other hand, projects as a peninsula some 400 miles southward from the Appalachian uplands, the southern tip of the peninsula being practically at the margin of the continental shelf. The maximum width of the Coastal Plain, some 600 miles, is in the Mississippi embayment. The Texas Coastal Plain is from 150 to 250 miles wide. The land slopes gulfwards, and no part of the region is mountainous. The structural features of the Texas Gulf Coastal Plain will be discussed under two headings, as follows: (1) pre-Mesozoic structural features, and (2) Mesozoic and Cenozoic structural features. The location of the principal structural features of this region is indicated in Figure 1, page 12, and Plate I (in pocket).

PRE-MESOZOIC STRUCTURAL FEATURES OF THE TEXAS GULF COASTAL PLAIN

LLANORIA LAND MASS OF PRE-CARBONIFEROUS TIME

A description of Gulf Coastal Plain structural features may well begin with an element of Gulf Coastal Plain structure which has not been seen and whose presence is inferred rather than known, namely, the Llanoria land mass, which underlies a part, no one can say just how much, of the present Texas Gulf Coastal Plain. The history of this land mass can be in some degree inferred. Repeated uplifts were necessary to supply the large quantity of sediments that was derived from it, although to what extent these uplifts were accompanied by structural deformation is unknown. The changes since Paleozoic time have resulted in a depression of this land mass much below sea level, coincident with the accumulation of many thousands of feet of overlying Mesozoic and Cenozoic sediments.

The existence of a land mass in the present Gulf Coastal Plain of Louisiana and Texas was postulated by Branner[6] as early as 1897 and has been referred to by many writers since that time.[7] Miser[8] in 1921 summarized the evidence bearing on the existence of this Paleozoic land area.

The evidence of such a land area may be considered first for pre-Carboniferous Paleozoic time. Naturally such evidence must be obtained largely from the sediments derived from the land mass. These sediments are exposed in the Ouachita Mountains of Oklahoma and in the Marathon and Solitario regions of Texas and are obtained from well cuttings at various places in the intervening region. The pre-Carboniferous sediments in these several areas are alike in that they consist very largely of clastic sediments and contain relatively little limestone. The problem, therefore, is to determine the location of the land mass from which the clastic materials were derived.

The source of materials of the early Paleozoic sediments of the Ouachita Mountains of Oklahoma and Arkansas is clearly indicated from the conglomerates and sandstones. The Crystal Mountain formation of Lower Ordovician age is chiefly sandstone with basal conglomerate. Honess[9] found that the basal conglomerate is absent, and the sandstone becomes fine grained to the north and northeast, indicating a southerly source for the materials. The Blakely sandstone appears abruptly above the Mazarn shale. Its outcropping area is of small extent, but Honess[10] concluded from his studies in Oklahoma that the source of the sand is from the southwest. This formation in Montgomery County, Arkansas, consists of sandstone

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[6]Branner, J. C., The former extension of the Appalachians across Mississippi, Louisiana, and Texas: Am. Jour. Sci., ser. 4, vol. 4, pp. 357-371, 1897.

[7]Reference to the principal literature on the Llanoria land mass is given in Vol. I, p. 21, footnote 8.

[8]Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: Am. Jour. Sci., ser. 5, vol. 2, pp. 61–89, 1921.

[9]Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Surv., Bull. 32, p. 54, 1923.

[10]*Op. cit.*, p. 62.

and shale. According to Miser,[11] the sandstone beds are lenticular and thin out to the north, whereas the beds of shales do not thin out in that direction. The Blaylock sandstone of Silurian age is found only in the south side of the Ouachita Mountains of Arkansas and Oklahoma. Miser's[12] conclusion regarding this sandstone is "that it was deposited in a minor east-west trough on the south side of the Ouachita geosyncline, that the northward thinning of the formation can be attributed in only a very small part to erosion, and that the land-derived sediments for it came from the south."

The other pre-Carboniferous formations of the Ouachita Mountains, the shales, cherts, novaculites, and some limestones, scarcely afford evidence as to the source of clastic materials. The information available from the sandstones, however, indicates a source from the south or southeast, and the deposits as a whole indicate fluctuating conditions. The conclusion is that sediments came from a land mass at the south or southeast and were accumulated in a bordering, fluctuating sea. The sediments of the same age in the foreland to the west contain extensive limestone beds.

The pre-Carboniferous sediments of the Marathon and Solitario uplifts, of which about 2600 feet are exposed, like those of the Ouachita Mountains include much clastic material. These sediments include some sandstones, conglomerates, boulder beds, and impure limestone with much shale, chert, and novaculite. Some of these sediments were evidently accumulated at no great distance from the shore line; others, such as the shales, may have been carried much farther from their source. The conditions under which such large amounts of chert and novaculite accumulate are not fully known.

In the foreland, 100 miles or thereabouts to the northwest of the Marathon region, the rocks of the Ordovician and Silurian are very largely limestones. Even within the limits of the Marathon basin the relative amount of limestone in the Lower Ordovician increases to the northwest.[13] The obvious explanation is that these clastic sediments were accumulated near the shore line of a land area. At the same time offshore to the northwest in clearer waters extensive limestones accumulated.

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[11]*Op. cit.*, p. 69.

[12]*Op. cit.*, p. 69.

[13]King, P. B., Pre-Carboniferous stratigraphy of Marathon uplift, west Texas: Bull. Geol. Soc. Amer., vol. 15, p. 1068, 1931.

Throughout the intervening area between the Marathon and Ouachita exposures the sediments in the geosyncline are largely clastic in character while away from the geosyncline in the foreland extensive limestones are present.

LLANORIA LAND MASS OF CARBONIFEROUS TIME

That a land mass existed to the south of the Ouachita Mountains and to the southeast of the Marathon region during a part of Carboniferous time is very well established. In the Ouachita Mountains the Stanley and Jackfork formations totaling 10,000 or 12,000 feet of sediments accumulated in early Pennsylvanian time. These formations thin to the north and west. The amount of sandstone in each formation becomes less to the north, and individual sandstone beds grade northward into shales.[14] These conditions imply an elevated land area at the south which was severely eroded to form these deposits.

In the Marathon region the Tesnus formation, which is of early Pennsylvanian age, thins from about 7000 feet at the southeast side of the Marathon region to a few hundred feet at the northwest side. The source of materials was obviously to the southeast. The Haymond formation of mid-Pennsylvanian time contains extensive boulder beds including very large erratics which were necessarily derived from a nearby source.

LLANORIA GEOSYNCLINE[15]

The Llanoria land mass formed the southern and eastern margins of the Paleozoic seas of central Texas, and from it were derived extensive deposits of clastic sediments forming a marginal or shore line facies in these seas. The position of the shore line changed from time to time, but, in the main, with successive orogenies, moved westward. This westward migration has been referred to by Ulrich[16] and has been very well brought out by Cheney.[17] The Cambrian formations exposed adjacent to the Llanoria land mass, the Collier

[14]Miser, H. D., *op. cit.*, p. 70.

[15]Reference to the principal literature relating to the Llanoria geosyncline and the sediments accumulated in it is given in Vol. I, p. 131, footnote 46.

[16]Ulrich, E. O., Revision of the Paleozoic systems. Bull. Geol. Soc. Amer., vol. 22, pp. 281-680, 1911.

[17]Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 557-594, 1929; and Stratigraphic and structural studies in north-central Texas: Univ. Texas Bull. 2913, 29 pp., 1929.

shale of the Ouachita region and the Dagger Flat sandstone and shale of the Marathon region, largely of clastic materials, are of unknown thickness, the base not being exposed. The succeeding Ordovician formations consist of sandstones, conglomerates, shales, and cherts, indicating fluctuating conditions. At times the shore line was near enough, or the elevation great enough, to result in deposition of sandstone with some conglomerate; at other times more quiet conditions prevailed, resulting in deposition of shales and, to a limited extent, limestones. Unusual conditions in Upper Ordovician time gave rise to extensive deposits of chert. Sands and muds were deposited during Silurian time, and in Devonian time extensive novaculite deposits accumulated.

The conditions of deposition of early Paleozoic sediments in the Marathon region clearly parallel those of the Ouachita region, although the Ordovician contains more limestone and less sandstone, and the Silurian, so far as known, is absent. The chert and novaculite deposits of the two regions present remarkable similarities. In both of these regions the deposits of Carboniferous time attain a great development, 20,000 or 25,000 feet in the Ouachita region and 12,000 or more feet in the Marathon region. The thickness of these sediments in the intervening region is unknown. The trough in which these Carboniferous sediments were accumulated appears to have extended uninterruptedly from the Ouachitas to the Marathon and Solitario regions.

The Ouachita region as a whole has been frequently referred to in the literature as the Ouachita geosyncline or Ouachita embayment, and, similarly, the Marathon basin of deposition as the Marathon geosyncline. Objection has, however, been made to referring to all of these sediments as having been deposited in a geosyncline since no exceptional thickness of early Paleozoic deposits is known.[18] The history of the whole area shows that the orogeny of this region moved progressively northwestward. Hence, the locality of the maximum thickness of pre-Carboniferous sediments may very possibly be to the east and south of the exposed areas of the Ouachita and Marathon regions. In any case, in early Pennsylvanian time the geosyncline centered in the Ouachita area and at the southeast side of the Marathon area. In the interest of more exact terminology

[18]Lloyd, E. R., letter of May 4, 1933

it may be best to define the Llanoria geosyncline as the trough which formed at the margin of the Llanoria land mass of Mississippian time and extended without interruption from the Ouachita to the Marathon and Solitario regions and received thick deposits of early Pennsylvanian sediments. The pre-Carboniferous sediments of these regions, if not geosynclinal, are at least marginal to the Llanoria land mass. The approximate location of the Llanoria land mass and Llanoria geosyncline is shown in Figure 1, page 12, of this volume. It is obvious that the boundaries of the Llanoria land mass changed from time to time through Paleozoic time. This fact has been emphasized by M. G. Cheney, who prefers to apply a distinctive name to the post-Bend land area. The sediments of the Llanoria geosyncline were intensely deformed in late Paleozoic time.

Since the sediments are now largely covered by Cretaceous, trend lines resulting from pre-Cretaceous deformation cannot be directly observed in central Texas from lack of exposures. Nevertheless, some evidence is available as to the trend of the structure lines in the syncline. The Ouachita Mountains of Arkansas and Oklahoma represent a part of the original great geosyncline, and in these mountains structural features, including folds and overthrust sheets, trend in general with the geosyncline. The Solitario and Marathon regions of Trans-Pecos Texas afford exposures in which structural trends of both overthrusts and folds are northeast-southwest. In addition, there is much evidence to show that the diastrophic forces by which these sediments were deformed thrust in the main northwestward, although, owing to the formation of salients and to the curved course of the main geosyncline, the thrust varies in direction from north to west, and the trends vary accordingly. These observations indicate that the structure lines trend approximately with the syncline.

SUMMARY OF PRE-MESOZOIC STRUCTURAL FEATURES IN THE GULF COASTAL PLAIN

1. The structural conditions of pre-Cambrian time in the present Texas Coastal Plain are entirely unknown. Certain suggestive hypotheses as to the grain of the Texas region have been advanced but will not be further discussed here.[19]

[19]Rettger, R. E., Interpretation of grain of Texas: Bull. Amer. Assoc. Petr. Geol., vol. 16 pp. 486–490, 1932.

Ruedemann, Rudolf, The existence and configuration of pre-Cambrian continents: New York State Mus., Bull. Nos. 239–240, pp. 65–152, 1922.

2. The land mass Llanoria occupied much of the present Coastal Plain region of Texas during most, if not all, of Paleozoic time. The approximate location of this land mass and its southwestward extension, the Columbian land mass, is indicated in Figure 10, page 128, of Volume I of The Geology of Texas, University of Texas Bulletin 3232, 1933.

3. A geosynclinal trough, the Llanoria geosyncline, receiving chiefly clastic sediments, existed at the western margin of this land mass during most of Paleozoic time.

4. The Llanoria geosyncline ceased to receive sediments and became a region of uplift and erosion as early as Strawn time. The evidence of uplift and erosion of these sediments is found in the presence of pebbles of the older Paleozoics of the geosyncline in the Strawn conglomerates of both the Brazos and Colorado river valleys.[20]

5. Within the Llanoria geosyncline, structural conditions are probably complicated, including folding, overturning, and thrusting. Owing, however, to the covering of Cretaceous, details of structure can seldom be obtained, and the time or times of structural deformation can seldom be determined beyond the observation already recorded that the geosynclinal sediments were subjected to erosion as early as Strawn time. Structural trend lines in the geosyncline are prevailingly northeast-southwest.

MESOZOIC AND CENOZOIC STRUCTURAL FEATURES OF THE TEXAS GULF COASTAL PLAIN

Within the Gulf Coastal Plain are three great embayments, the Mississippi, Northeast Texas, and Rio Grande. Of these, the two last named, known also as Nueces geosyncline and East Texas geosyncline, are largely in Texas. The relation of these embayments to the Mississippi embayment may be seen by consulting Figure 28, page 525, of Volume I.

RIO GRANDE EMBAYMENT[21]

The Rio Grande embayment or syncline, lying partly in Texas and partly in Mexico, as a whole has had a complicated history. As

[20]Bay, Harry X, A study of certain Pennsylvanian conglomerates of Texas: Univ. Texas Bull. 3201, pp. 149–188, 1932.

[21]Among publications relating to the structure of the Rio Grande embayment cited in the bibliography of Vol. I are the following: Adkins, 1444e; Baker, 45, 55, and 56; Böse and Cavins,

early as Upper Jurassic time an embayment, extending northwestward through central Mexico, entered western Texas (Vol. I, fig. 13, p. 277). An arm of this embayment extended northward in Coahuila. Subsequently, in Lower Cretaceous time, this original embayment was greatly enlarged until the Cretaceous seas covered all of Texas, as well as large parts of adjoining states and much of Mexico, the maximum deposition, however, being in Mexico. Conditions of earliest Upper Cretaceous time, Woodbine group, in this region are imperfectly known, but by Eagle Ford time the syncline had assumed approximately its present position. Thick sediments, shales, cherts, and marls, accumulated during Upper Cretaceous time, including, near the end of this epoch, coal deposits and other evidence of near-shore conditions.

The embayment persisted through the Cenozoic during which time the Coastal Plain as a whole gradually emerged above sea level. The indentation of the coast line incident to the present embayment is most pronounced in Nueces, Kleberg, and Kenedy counties and has been somewhat modified by the delta at the present mouth of the Rio Grande. Minor structural features are found within this large embayment, some of which are subsequently described.

That the region of this embayment was structurally low in Texas during Lower Cretaceous time is believed to be indicated by the great thickness of sediments, 10,000 feet or more,[22] that accumulated during that time as compared to the lesser accumulation in regions in the Texas Coastal Plain not in the embayment.

The sediments of Lower Cretaceous Comanche series in this syncline, aside from the basal sands, are chiefly calcareous, including limestones and marls with some anhydrite and salt. The limestones and marls as well as the anhydrite and salt are probably largely of shallow water deposition. Distinctly shaly sediments are found in the Del Rio formation near the close of the Comanche series. The shales are succeeded by the Buda limestone. The overlying Gulf series contains shales, chalks, and marls. The succeeding Eocene sediments are very largely of clastic materials. A well drilled on

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135; Deussen, 421; Dumble, 502a; Getzendaner, 578 and 578a; Hill, 803 and 826; Jones, 886b and 892; Roberts and Nash, 1324; Stephenson, 1531 and 1537; Tatum, 1590 and 1590a; Trowbridge, 1610 and 1613a; Udden, 1625; Vanderpool, 1681.

[22]Vanderpool, H. C., Cretaceous section of Maverick County, Texas: Jour. Pal., vol. 4, pp. 252-258 1930

the Pratt ranch in the western part of Webb County in this embayment, starting in the Cook Mountain formation, terminated in the Midway at depth 5033 feet. The full thickness of the Eocene at this locality is evidently considerably in excess of 5000 feet. A well located near Guerrero in the state of Tamaulipas, Mexico, is reported to have shown that the Midway formation at that locality is more than 4000 feet thick. The combined thickness of Cretaceous and Eocene sediments in this embayment, therefore, cannot be less than 15,000 feet and may exceed 20,000 feet. For location of counties referred to in this and succeeding discussion see Plate I (in pocket).

Some well marked structural features in Texas have been recognized in this great embayment. The Chittim anticline, named by Vanderpool[23] in 1930, trends northwest-southeast through Maverick County and into Dimmit County. Northeast of the anticline in eastern Maverick and Zavala counties is a broad syncline named La Pryor by Trowbridge which likewise trends southeast. The mild folds involve Cretaceous and Eocene formations. The Chittim anticline plunges southeast and the associated La Pryor syncline spoons out at the northwest. In 1922 Stephenson[24] called attention to an anticline in Val Verde County extending west by north passing near Del Rio. This anticline is formed in Cretaceous strata.

The disposition of the streams suggests that the present drainage within the embayment may have been affected by recent uplift. Thus, the Rio Grande is located not centrally in the present embayment but flows near its southern margin. All tributaries entering the Rio Grande from the north within the embayment are short. Only near the head of the embayment, where Pecos River enters, is there extended drainage from the north. On the other hand, Nueces River, coming from the north, flows approximately in the center of the present embayment through Dimmit and La Salle counties, turns abruptly northeast through McMullen County, and again turns southeast to reach the coast at Corpus Christi. Tributaries of the Nueces control drainage to within a few miles of the Rio Grande.

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[23]Vanderpool, H. C., *op. cit.* This structural feature was called Carrizo Springs anticline by Trowbridge in 1932, U. S. Geol. Surv., Bull. 837, p. 237.

[24]Stephenson, L. W., A chance of more oil in southwestern Texas: Bull. Amer. Assoc. Petr. Geol., vol. 6, pp. 475–476, 1922.

NORTHEAST TEXAS EMBAYMENT[25]

The Northeast Texas embayment or syncline includes a large region of the Coastal Plain of northeast Texas. This embayment has passed through a complicated history which at best is but partly known. Its structural pattern is affected by the Sabine uplift located in the Coastal Plain of western Louisiana and Texas. The time of the origin of the embayment is in doubt. Underlying much of the basin are salt deposits from which numerous salt domes have been formed constituting the inner salt dome province of the Texas Coastal Plain. This salt, in the writer's opinion, was probably formed in this embayment at a time when it was cut off from free communication with the sea. This assumption, however, as to the age of the salt cannot be proven by any data yet obtained, and some geologists assign a Paleozoic age to the salt. On the assumption that the salt originated in this basin, the time of origin of the basin must be placed as not later than early Cretaceous or even possibly in Jurassic time. The Cretaceous is known to contain anhydrite in this region, contains anhydrite and some salt in the Rio Grande embayment, and is reported to contain salt in Mexico.[26] Early Cretaceous seas or possibly Jurassic seas, if there were such in any part of the Texas Coastal Plain, may have deposited the salt beds from which the salt domes were formed.

The east Texas syncline persisted as an embayment until near the close of Eocene. The Oligocene formations present no marked indentation crossing this region. The present Red River flows at the north margin of the embayment. The Lower Cretaceous sediments of this embayment lack the extensive limestones found in the Rio Grande embayment and include instead deposits of sand, red clay, and extensive anhydrite beds. A well drilled by the Amerada Petroleum Corporation (No. 1 Wade) in Upshur County in this embayment starting in the Eocene was drilled to total depth 6153

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[25]Among publications relating to the structure of the Northeast Texas embayment cited in the bibliography and subject index of Vol. I are the following: Bullard, 177; Cheney 247d; Fohs, 543; Fohs and Robertson, 542; Gordon, 609; Hill, 753, 774, 788, and 803; Hopkins, Powers, and Robinson, 844; Lahee, 964 and 969; Plummer and Sargent, 1234b; Robinson, 1326; Stephenson, 1530 and 1537; Veatch, 1688c.

[26]Burrows, R. H., Geology of northern Mexico: Bol. Soc. Geol. Mexicana, vol. 7, p. 96, 1910; and Burckhardt, Carlos, Etude synthétique sur le Mesozoique mexicain: Soc. Pal. S., Mém. 49–50, 280 pp., 1930. Both Burrows and Burckhardt refer to this salt as being in the Cuchillo formation, equivalent to Travis Peak. However, W. S. Adkins, who has visited the locality, states that the salt is in the Las Vigas formation which is Cretaceous older than the Travis Peak.

feet, at which depth it is believed to have been within about 100 feet of the anhydrite zone of the Glen Rose formation.[27] A well drilled by the Pure Oil Company in the Van oil field in Van Zandt County, starting in the Eocene, drilled to a depth of 7501 feet, passed through the anhydrite zone, and terminated in sands underlying the Glen Rose limestone.

The axis of the embayment of Upper Cretaceous time probably trended northwest-southeast.[28] This trend is recognizable when the region is contoured on the Woodbine sand. The present structural basin, however, in its southern part trends approximately north-south but swings northeast to pass between the Sabine uplift and the Ouachita region, there connecting with a basin in Arkansas. In the Smackover oil field in this connecting basin in Arkansas a well, drilled to a total depth of 7255 feet, terminated in salt which was first encountered at depth 5220 feet. Above the salt are Cretaceous and Tertiary formations.[29] The age of the salt is unknown. For the structural features of the Northeast Texas embayment contoured on the Woodbine formation, see map accompanying University of Texas Bulletin 3138.[30] For further discussion of structural conditions in this embayment, see papers on iron ore deposits by Baker and by Eckel and Purcell in this volume.

The Preston anticline involving Cretaceous and Eocene formations comes into Texas near the head of this embayment and trending southeast is traceable through Grayson and Fannin counties. This anticline and associated structural features have been fully described by Stephenson, Hopkins, and others.[31]

The great east Texas oil field, near the east margin of this embayment, is the result of a favorable combination of structural and stratigraphic conditions. Structurally the field is located on a

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[27]Denison, A. R., Oldham, A. E., and Kisling, J. W., Jr., Structure and stratigraphy of the Kelsey anticline, Upshur County, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 17, p. 664, 1933.

[28]Stephenson, L. W., Structural features of the Atlantic and Gulf Coastal Plain: Bull. Geol. Soc. Amer., vol. 39, p. 892, 1928.

[29]Bell, H. W., Discovery of rock salt deposit in deep well in Union County, Arkansas: Arkansas Geol. Surv., Inf. Circ. 5, 31 pp., 1933.

[30]Plummer, F. B., and Sargent, E. C., Underground waters and subsurface temperatures of the Woodbine sand in northeast Texas: Univ. Texas Bull. 3138, 178 pp., map, 1931.

[31]Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Surv., Prof. Paper 120, pp. 129–163, 1918.

Hopkins, O. B., Powers, Sidney, and Robinson, H. M., The structure of the Madill-Denison area, Oklahoma and Texas, with notes on oil and gas development: U. S. Geol. Surv., Bull. 736, pp. 1–33, 1922.

broad arch projecting westward from the Sabine uplift. Favorable stratigraphic conditions are Woodbine sands pinching out between relatively impervious strata. The Balcones and Mexia fault zones which come into this embayment are described subsequently.

SAN MARCOS ARCH

Separating the Rio Grande and Northeast Texas embayments is the San Marcos arch. In the discussion of deformational movements of pre-Paleozoic time mention was made of the northwest-southeast trending folds of the Llano region. In the discussion on Central Texas attention will be called to a renewed movement essentially on the same trend in the formation of the Concho arch of Upper Pennsylvanian time. Whether or not these movements of pre-Cambrian and Upper Pennsylvanian time extend far enough to the southeast to enter the Gulf Coast region is unknown. However, the deposition of sediments in the Cretaceous seas records the presence of a positive element essentially in the trend of these uplifts. This arch in the Coastal Plain region was submerged during most of Lower and Upper Cretaceous time but its presence is made known by thinning of some of the Cretaceous formations. This thinning is best recorded in Upper Cretaceous formations and is observed in the Georgetown formation of the Lower Comanche series. To what extent this arch affects Cenozoic formations and how far gulfward it extends is less well determined.

The approximate location of the arch is indicated in Figure 28, page 525 (Vol. I). However, as judged by its influence on the Cretaceous formations, it was not an arch of slight width but was rather a broad positive element resulting in the thinning especially of the Upper Cretaceous formations in several counties including Travis, Hays, Comal, Caldwell, Guadalupe, Bexar, and Medina. This arch is indicated on a map by Stephenson[32] issued in 1928. The term San Marcos arch was proposed by Adkins in Volume I. page 266, 1933.

The basal Upper Cretaceous Woodbine formation is absent from the San Marcos arch and generally from this part of the state or, if present at all, is represented only locally by no more than a thin

[32]Stephenson, L. W., Structural features of the Atlantic and Gulf Coastal Plain Bull. Geol. Soc. Amer., vol. 39, pp. 887–899, 1928.

stratum.[33] The Eagle Ford, which in the Rio Grande Valley and in northeast Texas is 500 or more feet thick, thins across this arch to a minimum of about 25 feet. The thinning is gradual approaching this region. The thinned Eagle Ford, according to Adkins (Vol. I, p. 435), is a condensed zone and represents most, if not all, of the Eagle Ford formation. If this interpretation is correct the broad arch received sediments very slowly during Eagle Ford time, presumably because it stood higher than the embayments at either side. Thinning is seen also in the other Upper Cretaceous formations, the Austin, Taylor, and Navarro, but not in so pronounced degree as in the Eagle Ford.

SABINE UPLIFT[34]

The Sabine uplift is a large dome in northwestern Louisiana, the western slope of which extends into Texas, there forming the eastern limit of the Northeast Texas embayment (Pl. I). No wells have as yet been drilled into pre-Cretaceous rocks on this uplift, and the pre-Cretaceous history of the uplift is unknown. The Lower Cretaceous was deposited across the site of the present uplift,[35] indicating that the uplift had not then been formed or, if so, had been so completely truncated by erosion as not to be at that time a topographic high. At or near the close of the Lower Cretaceous this region was uplifted and subjected to erosion so that the Upper Cretaceous is separated from the Lower by a profound unconformity. After erosion in some parts of the uplift had removed much of the Lower Cretaceous, the region was again covered by the Upper Cretaceous seas. Within the Upper Cretaceous are shore line facies and depositional breaks, and at the close of the Upper Cretaceous is another depositional break with erosion over an extensive region.[36]

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[33]Stephenson, L. W., Notes on the stratigraphy of the Upper Cretaceous formations of Texas and Arkansas: Bull. Amer. Assoc. Petr. Geol., vol. 11, p. 3, 1927.

[34]Among publications relating to the Sabine uplift cited in the bibliography of Vol I are the following: Cheney, 247d; Dumble, 506; Harris, 665b; Huntley, 861; Moody, 1125; Powers, 1248 and 1252; Stephenson, 1532b and 1537; Van der Gracht, 1677; Vance and Fagin, 1675b; Veatch, 1691.

[35]Cheney, M. G., East Texas paleogeography and oil migration: Pan-American Geol., vol. 57, p. 307, 1932.

Van der Gracht, W. A. J. M. van Waterschoot The Permo-Carboniferous orogeny in the south-central United States: Koninklijke Akademie van Wetenschappen te Amsterdam, Deel 27, no. 3, p. 125, 1931.

[36]Moody, C. L., Tertiary history of the Sabine uplift, Louisiana: Bull. Amer. Assoc. Petr Geol., vol. 15, p. 538, 1931.

The Tertiary history of the uplift is likewise complicated, including successive uplifts.

This erosional break at the close of Comanche Cretaceous time is indicated in the accompanying section. This illustration has been prepared by R. T. Hazzard who is of the opinion that as much as 2000 feet of the Trinity is missing at the top of the Homer dome, this region having been deformed and eroded prior to deposition of the Gulf series of the Cretaceous. The missing Trinity sediments include the "upper Trinity red," upper Glen Rose, Glen Rose anhydrite, lower Glen Rose, and 600 feet of the "lower Trinity red." The Louisiana Oil and Refining Company No. 10 Langston well on this dome passed directly from the Gulf series into the "lower Trinity red." The "lower marine" Cretaceous was reached in this well at depth 3700 feet and the well terminated in these sediments at depth 4504 feet. (R. T. Hazzard, letter of January 12, 1934.)

The wells used in this section are as follows:

Name of company and well	Location S. T. R.	
1. Artex Oil Co., Smith 1	31–15–17	Ouachita Co., Ark.
2. Arkansas Investment Co., McRae 1	16–16–18	Union Co., Ark.
3. Thos. J. Bush, Tr., Jones 1	5–17–18	Columbia Co., Ark.
4. Gulf Refining Co., Hines 1	17–17–18	Columbia Co., Ark.
5. Pat Marr, Hollingsworth 1	6–18–18	Columbia Co., Ark.
6. Colquitt-Thomas, Duffer 1	23–18–19	Columbia Co., Ark.
7. J. E. Kent et al, Emerson Estate 1	7–19–19	Columbia Co., Ark
8. Talbot Markle, Copeland 1	31–19–19	Columbia Co., Ark.
9. Ohio Oil Co., Waller 2	2–23–8	Claiborne Parish, La.
10. Gilliland Oil Co., Waller 7	11–23–8	Claiborne Parish, La.
11. Gilliland Oil Co., Taylor "D" 1	14–23–8	Claiborne Parish, La
12. Haynes Bros., Braselton 1	27–23–8	Claiborne Parish, La.
13. Clark & Greer, Hearne 1	3–22–8	Claiborne Parish, La.
14. Magnolia Petroleum Co., Lee 1	16–22–8	Claiborne Parish, La.
15. Simms Oil Co., Avinger 1	25–22–8	Claiborne Parish, La.
16. Homer-Mansfield Oil Co., Hollingshead 1	11–21–8	Claiborne Parish, La.
17. Standard Oil Co., Nunnelly 1	18–21–7	Claiborne Parish, La.
18. Gulf Refining Co., Langston 15	19–21–7	Claiborne Parish, La.
19. Louisiana Oil Refining Corp., Langston 10	19–21–7	Claiborne Parish, La.
20. Standard Oil Co., Shaw-Palmer 50	30–21–7	Claiborne Parish, La.
21. Louisiana Oil Refining Corp., Merritt 1	32–21–7	Claiborne Parish, La.
22. Homer Amalgamated Oil & Refining Co., Kinnebrew 1	5–20–7	Claiborne Parish, La.
23. Geo. Baird, Gladney 3	14–20–7	Claiborne Parish, La.
24. Eldorado Chief Oil Co., Baker 1	26–20–7	Claiborne Parish, La.
25. Mitchell-Jensen, Wilbourn 1	23–19–7	Claiborne Parish, La.

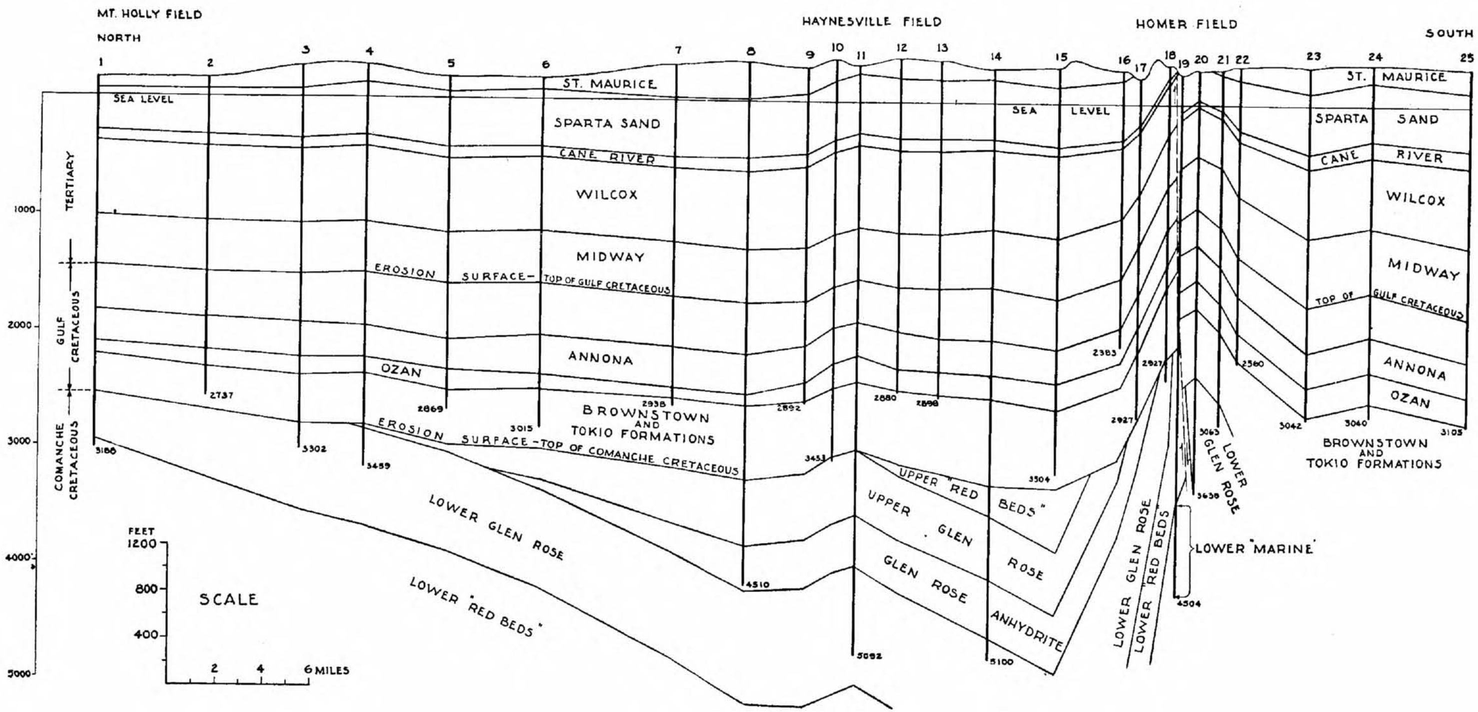

Fig. 4. North-south section through Mt. Holly, Haynesville, and Homer oil fields in Louisiana illustrating erosional unconformity at top of the Comanche Cretaceous; also faulting in the Homer dome.

The Sabine uplift contoured on the top of the Nacatoch sand of the Upper Cretaceous series has a distinct northwest-southeast trend. There is recognizable also a less pronounced northeast-southwest trend.[37] The Monroe uplift of Arkansas and Louisiana, which also trends northwest-southeast, parallels the Sabine uplift and is a part of the greater uplifted region of northwestern Louisiana and adjacent parts of Texas and Arkansas.[38]

The east Texas embayment, which had originally a northwest-southeast axis, was modified by the formation of the Sabine uplift so as to trend in part north-south, its northern part being deflected to the northeast. The present structural trough has been called the Tyler syncline.

MONOCLINAL FOLDS AND FLEXURES

In the Gulf Coastal Plain are two flexures or monoclinal folds of regional extent. One of these, best known in Williamson and adjoining counties, has been indicated by Deussen.[39] In Williamson County the dip measured in the Upper Cretaceous formations west of this monocline is 90 or 100 feet per mile. East of Thrall, which is the approximate location of the beginning of the monoclinal slope, the dip in the same formations is 150 or 200 feet per mile.

The Angelina-Caldwell flexure, chiefly in Louisiana south of the Sabine uplift, is described by Veatch[40] as extending into Texas. This flexure is made evident in the region of Sabine River by appreciably increased southward dips in the Eocene formations. According to Schneider,[41] Eocene formations which north of the flexure have a very gentle dip increase in dip, in Sabine Parish, Louisiana, in the zone of flexure to as much as 180 feet per mile.

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[37]Powers, Sidney, The Sabine uplift, Louisiana: Bull. Amer. Assoc. Petr. Geol., vol. 4, fig. 1, p. 119, 1920.

Spooner, W. C., Interior salt domes of Louisiana: Bull. Amer. Assoc. Petr. Geol., vol. 10, map facing p. 217, 1926.

Fletcher, C. D., Structure of Caddo field, Caddo Parish, Louisiana: Structure of Typical American Oil Fields, Vol. II, fig. 1. p. 185, 1929.

[38]Huntley, L. G., The Sabine uplift: Bull. Amer. Assoc. Petr. Geol., vol. 7, pp. 179–181, 1923.

[39]Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Surv., Prof. Paper 126, map, p. 132, 1924.

[40]Veatch, A. C., The geography and geology of the Sabine River, *in* A report on the geology of Louisiana: Louisiana Geol. Surv., vol. 6, pp. 101–148, 1902; and Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Surv., Prof. Paper 46, p. 68, 1906.

[41]Schneider, G. W., Urania oil field, LaSalle, Winn, and Grant parishes, Louisiana: Structure of Typical American Oil Fields, Vol. I, p. 96, 1929.

BALCONES ZONE OF FAULTING AND FOLDING[42]

INTRODUCTORY STATEMENT

A paleoplain of Mesozoic time, originally described by R. T. Hill,[43] included a part, possibly the greater part, of the present Texas Coastal Plain. This paleoplain was developed across two or three kinds or facies of rock formations. At the east was probably chiefly pre-Cambrian basement rocks of the Llanoria land mass with possibly some Paleozoic rocks; next west or northwest was a relatively narrow belt of Paleozoic clastics lying in the Llanoria geosyncline; and, occupying much of central Texas, were Paleozoic sediments containing heavy limestone formations. Subsequent eastward tilting during Mesozoic and Cenozoic time lowered the eastern margin of this plain several thousand feet below sea level. Extensive faulting and folding developed incident to this tilting. Of the several resulting structural zones the Balcones zone is the westernmost and forms through much of Texas the inner margin of the Gulf Coastal Plain.

The Balcones structural zone lies in greater part within the Gulf Coastal Plain, near its inner margin, and in lesser part in the adjoining Edwards Plateau. This zone, as a structural feature, is traceable in Texas from near Del Rio in Val Verde County to somewhat north of Waco in McLennan County. Through Kinney and Uvalde counties and into Medina County its course is easterly, thence east-northeast through Medina and Bexar counties and into Comal County, thence north-northeast through Comal, Hays, Travis, Williamson, Bell, and McLennan counties. This zone has not been definitely recognized north of McLennan or Hill counties. However, Barton reports that he has traced a zone of much fracturing and minor faulting northward from Waco passing near Italy in Ellis County, east of Whiterock Reservoir in Dallas County, and near McKinley in Collin County (letters of March 9 and 27, 1934).

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[42]Among publications relating to the Balcones fault zone cited in the bibliography and subject index of Vol. I are the following: Adkins, 11; Adkins and Arick, 16; Baker, 49; Brucks, 164; Collingwood and Rettger, 267; Cope, 290a; Cuyler, 384; Deussen, 421; Fohs, 543; Fohs and Robinson, 542; Foley, 544; Hill, 732, 743, 750, 761, 766, and 803; Hill and Vaughan, 794, 795, and 808; Jones, 889a; Liddle, 992 and 992a; Link, 999; Lonsdale, 1009; Pratt and Lahee, 1263; Robinson, 1326; Sellards, 1401, 1402, 1407, and 1441; Udden, 1651; Udden, Baker, and Böse, 1652; Vaughan, 1686.

[43]Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, p. 363, 1901.

Essentially in this line are faults east of Forreston in Ellis County noted by Hill, and east of Abbott in Hill County noted by Adkins. Farther to the east a line of faulting passes near Mount Calm in Hill County. Small faulting is not uncommon over a wide belt north of Waco. That noted by Hill between Whitney and Aquilla in Hill County and by Brantly near Venus at the Johnson-Ellis county line is possibly west of the principal Balcones zone. In Rockwall and Collin counties are numerous sandstone dikes which trend in the main north-northeast. Possibly the Mount Calm fault line, rather than the Balcones proper, connects with these dikes of Rockwall and eastern Collin County. Similar sandstone dikes have recently been reported in Falls County.

Faulting in the Balcones zone is most pronounced from near Uvalde in Uvalde County to Austin in Travis County. This pronounced faulting is within the region where the zone is curving around the Llano uplift. West of Uvalde, through Kinney and Val Verde counties, the faulting is reduced, and the structural feature becomes a monocline with some faulting. North of Austin the faulting is also reduced, and the actual tracing of the zone becomes difficult north of McLennan County. The Balcones zone, viewed as a whole, is thus seen to be divisible into three parts as follows: in the southwestern part, a monoclinal fold; in the central part, a zone of pronounced faulting; and in the northeastern part, a zone of minor faulting with probably somewhat accentuated dips indicating monoclinal folding. All the faults observed in Balcones zone are believed to be normal or gravity faults. If this zone continues westward beyond Val Verde County it meets the zone of Cordilleran folding approximately at right angles. If it continues northeastward it passes into the region of the Ouachita folds and thrust-faulting of Oklahoma.

Associated with the Balcones zone, and with the Mexia zone which approximately parallels it, are extensive intruded or extruded igneous masses. These igneous rocks are found chiefly, if not entirely, in the region of pronounced faulting from Kinney to Williamson counties. The igneous masses are not confined to the known faults of these zones but occur for many miles on both sides of the large or main faults. Nevertheless, it is probable that they have a relationship to the zones of faulting.[44]

The Balcones escarpment as a topographic feature was, of course, observed from the time of the earliest settlements in this part of Texas, and the numerous springs that emerge in this zone resulted in early settlements at San Antonio, New Braunfels, San Marcos, and Austin. The Balcones scarp, without name, was shown on Humboldt's map of 1812 and on Roemer's map of 1849.

Faulting in this zone seems to have been first recorded by Cope[45] in 1880. Cope says: "An abrupt elevation commences somewhere to the southwest of Fort Worth and continues southward and westward, passing close to Austin, the State capital, and within twenty miles of the city of San Antonio, extending westward to the Rio Grande. . . . the fault which should exist has been observed at various lines along the elevation. I found it crossing the Heliotes Creek, eighteen miles west of San Antonio, at a locality pointed out to me by Mr. Gabriel W. Marnoch." This brief mention of the faulting, made in a zoological paper, apparently passed unnoticed among geologists until revived and quoted by Hill[46] in 1887. The paper by Hill in which this quotation occurs is devoted largely to disproving Roemer's and Shumard's contention that the Cretaceous of the Coastal Plain was older than and passed under that of the hill country. This apparent, not real, relationship of the formations is due, of course, to the Balcones faulting which had not been recognized by Roemer and Shumard.

In a paper published in 1889, Hill[47] described faulting west of Austin and stated that this fault line extends southwest to the Rio Grande. He noted the associated springs and indicated faulting on map and cross section. To establish faulting in this zone in opposition to the then accepted authority of Roemer and Shumard was a most difficult task. Roemer, shortly before his death, stoutly protested any such faulting (letter to R. T. Hill).

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[44]Sellards, E. H., Rocks underlying Cretaceous in Balcones fault zone of central Texas: Bull. Amer. Assoc. Petr. Geol., vol. 15, pp. 819–827, 1931.

[45]Cope, E. D., On the zoological position of Texas: U. S. Nat. Mus., Bull. 17, 51 pp., 1880.

[46]Hill, R. T., The Texas section of the American Cretaceous: Amer. Jour. Sci., vol. 34, pp. 292–293, 1887.

[47]Hill, R. T., A portion of the geologic story of the Colorado River of Texas: Amer. Geol., vol. 3, pp. 295–296, May, 1889.

The name "Balcones," in connection with the Balcones lineament, seems to have first appeared in print upon a map entitled "An approximate map of the topography and geology of the Texas region," by R. T. Hill, Bulletin University of Texas, December, 1889.[48] The first use of the term Balcones in application to the fault line was made by Hill[49] in 1889, published in January, 1890. In this paper Hill noted that the margin of the then unnamed Edwards Plateau was a fault scarp and again commented on the relation of the springs to the faulting. He also associated the igneous rocks with the faulting and gave them the name of Shumard Knobs. In this paper also Hill states that the Spanish people called the scarp "El Balcones." However, he now believes this was an error and that he took the name "Balcones" from Balcones Creek which forms a part of the northern boundary of Bexar County (letter of June 25, 1933). The first cross section showing details of faulting was published in 1890.[50] Subsequent publications developing the knowledge of this zone are too numerous to cite in this volume but are included in the bibliography of Texas geology contained in Volume I.

DESCRIPTION OF FAULTING BY COUNTIES

It is desirable to gain, if possible, more information as to the exact condition of faulting in this zone and to trace out more fully the several faults and groups of faults. Such information, necessary to a full understanding of the mechanics of faulting in this zone, is hampered by lack of accurate detailed maps and by the need of more complete tracing of faults on the ground, made difficult by the superficial covering that conceals so many of the faults. For these reasons, generalizations made at this time are sure to require revision as the zone is more fully studied. Nevertheless, that complicated structural conditions exist in this zone is evident, and some of the relationships may now be pointed out. For location of the Balcones and Mexia zones and some of the larger faults see Plate I (in pocket).

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[48]This bulletin, which was without number, contained two papers: *The history and burden of taxation*, by O. M. Roberts; and Roads and material for their construction in the Black Prairie region of Texas, by R. T. Hill.

[49]Hill, R. T., *Classification and origin of the chief geographic features of the Texas region*: Amer. Geol., vol. 5, pp. 17–19, 1890.

[50]Hill, R. T. A brief description of the Cretaceous rocks of Texas: Texas Geol. Surv., 1st Ann. Rept. p. 135, 1890.

In the following observations the zone is discussed in Texas from southwest to northeast. In Val Verde County some faulting may occur at Del Rio, accounting for San Felipe Springs at that place, but at best relatively little faulting occurs in the Cretaceous in Val Verde County. C. L. Baker reports that the structural feature is a monocline at the crossing of the Rio Grande near Del Rio, the dip to the south approximating 5°. No igneous rocks are known in this zone in Val Verde County.

Kinney County, next to the east, is more distinctly affected by this structural zone. Hill and Vaughan[51] have called attention to the structurally disturbed conditions in the southern part of the Nueces quadrangle, that is, the northeastern part of Kinney County. In this connection they name, but do not describe, several structural features, among which are the Griffin monocline, Little Pinto fault, Whistler fold, Elm fault, and Turkey fold. F. M. Getzendaner (letter of May 17, 1933) states that the displacement of the Elm fault at the West Fork of the Nueces is as much as 100 feet. At Las Moras Springs at Brackettville there is very little displacement. Getzendaner states also that he has observed small faulting west of Brackettville at Mud Springs. He associates these faults with a large structural feature which he has named the Brackett anticline. It is also reported by Getzendaner that on the West Fork of the Nueces, near the Kinney-Uvalde county line, a horizon 100 feet down in the Edwards is faulted against Eagle Ford. To the southwest this fault dies out near Turkey Mountain. The Balcones zone in Kinney County is apparently a broad east-west-trending monocline crossing the central part of the county, the regional dip being to the south. Within the broad monocline is the Brackett anticline which strikes northeast-southwest and some faults of relatively small displacement trending northeast-southwest on the flanks of the anticline. Associated with this structural zone in the central and eastern parts of the county are several igneous sills and plugs.

In Uvalde County the Balcones zone becomes highly complicated, including much faulting and many igneous plugs. In the northern part of the county a fault, trending northeast, crosses into Bandera County near the southwest corner of the county (F. M. Getzendaner,

[51]Hill, R. T., and Vaughan, T. W., Description of the Nueces quadrangle: U. S. Geol. Surv., Geol. Atlas, Nueces folio (No. 42). p. 2 1898.

personal statement). Small faulting, possibly of the same sub-zone, has been reported a few miles south of west of Bandera. The fault already referred to as extending eastward from Turkey Mountain in Kinney County probably continues into Uvalde County. Near the old "silver mine" in the northern part of the Uvalde folio, Vaughan[52] has described displacement either by sink formation or by faulting, bringing the Del Rio almost to the level of the Comanche Peak. Continuing eastward, some faulting is seen at the extreme northeast part of this folio which continues with northeast trend into Medina County. Crossing near the central part of Uvalde County is a more nearly continuous line of faulting which is probably of larger displacement than the faults farther to the north. The trend of this sub-zone of faulting in the western part of the county is nearly east-west, but from near Uvalde the faults trend northeast into Medina County.

In central Uvalde County is a pronounced structural feature for which Jeffrey proposed the name Uvalde Salient. The most pronounced, as well as the most complicated, faulting in the county, if not in the whole Balcones zone, occurs on and around the margins of this structural feature. Of this structural feature, Getzendaner[53] says: "Measured on the exposed Comanchean alone, the Uvalde Salient extends 11 miles southward from the main line of the Balcones fault and is about 7 miles wide at the town of Uvalde. On younger beds both dimensions are much greater. . . . At the southern end of this Comanchean extension, Escondido (Navarro in age) is downthrown on a level with the Edwards limestone by a zone of faulting 1 to 2 miles wide and 8 miles long, the displacements aggregating about 1300 feet within less than two miles."

While the faulting is complicated, there is a tendency for the faults at either side of the salient to parallel its axis. Not only are the structural conditions and the faulting complicated in this region but the associated igneous masses are likewise more numerous in the Uvalde region than elsewhere in the Balcones zone.

Faulting in the extreme northern part of Medina County does not appear to be very pronounced. However, in the vicinity of Cliff,

[52]Vaughan, T. W., Description of the Uvalde quadrangle (petrographic description of igneous rocks by Whitman Cross): U. S. Geol. Surv., Geol. Atlas, Uvalde folio (No. 64), 7 pp., 1900.

[53]Getzendaner, F. M., Mineral resources of Texas: Uvalde, Zavala, and Maverick counties (preprint): Bureau of Economic Geology, p. 97, 1931.

near the Bexar County line, very heavy faulting occurs, interpreted as being associated with the Culebra structural feature of Bexar County. In the vicinity of Noonan are numerous faults, which are approximately in line with, and possibly represent, the southwestward extension of the San Antonio structural feature of Bexar County. In the southeastern part of Medina County are faults which are possibly associated with the Alta Vista structural zone.

Faulting in Bexar County is more or less associated with three pronounced structural features to which the writer[54] several years ago applied the names Culebra, San Antonio, and Alta Vista. The Culebra structural feature extends from the north-central part of Bexar County southwestward into Medina County. It is bounded at the west by the most pronounced faulting in Bexar County, the Taylor formation being brought to the level of the Glen Rose or nearly so. Large faulting at the west margin extends from near Helotes in a southwesterly direction to and beyond Cliff in Medina County. The faults at the east side are of lesser displacement and are difficult to trace as much of the bed rock is concealed by terrace deposits. As a whole the Culebra structural feature is a southwest plunging anticline. In detail, however, it probably contains several local highs. The axis of the anticline parallels the trend of the major faults.

The San Antonio structural feature trends southwest through the city of San Antonio. In and near San Antonio it is very much broken by faulting. Such of these faults as were then known, either from surface exposures or from well records, were described by the writer in 1919. The complexity of faulting in this region, however, is even yet only partially deciphered. Alamo Heights north of the city limits of San Antonio is located on an upthrown block, or horst, which brings the Austin chalk to the surface. Faults at the west side of the horst, with downthrow to the west, trend S. 20° to 35° W. A fault at the east side with downthrow to the east trends about S. 60° W. The intersection of these two fault trends terminates this particular horst. This intersection comes in part near San Pedro Springs and in part, there being more than one fault at the west side, near the lake next east of Our Lady of the Lake College

[54]Sellards, E. H., The geology and mineral resources of Bexar County: Univ. Texas Bull. 1932, pp. 82–86, 1919

in the western part of San Antonio. The basin of this lake is probably a sunken block. The San Antonio structural feature, with faults downthrown to the west at its west side, is essentially of the Mexia fault zone type. In its southwestward extension in the Gas Ridge field, folding is more definitely exhibited, the exposed formation being the Upper Cretaceous clays and marls. Here, however, relationship to the Mexia zone of folding is seen in small faulting with downthrow to the west and in the probable presence of a graben separating the San Antonio and Culebra structural features. Cross faults probably cut this structural feature. The conditions in the Adams gas field of Medina County, interpreted as the southwestward extension of the same structural line, are less well known. Apparently the structural line is there in part dissipated by much small scale faulting.

The Alta Vista structural feature which approximately parallels the two described is limited at the west side by a large fault downthrown to the west. In this respect this zone is in agreement with the Mexia structural zone. The Alta Vista structural feature, like the other major structural features of Bexar County, plunges southwest and apparently continues to and is responsible for the Somerset oil field of Atascosa County.

Whitney and Cuyler report some faulting with northeast trend in the western part, and a persistent sub-zone of faulting crossing the central part, of Comal County (manuscript). The most pronounced faulting in the county, forming a large escarpment, occurs at and near New Braunfels and trends northeast into Hays County. A few miles west of New Braunfels is a small area of very complicated faulting.

A zone of small faulting, continuing from Comal County, enters Hays County, according to Whitney (manuscript map), near Purgatoire. This sub-zone trends north-northeast and leaves the county near Johnstons Institute. The faults are of relatively small throw, and the zone of faulting is not complicated. Several miles farther to the east, at the margin of the Coastal Plain in the vicinity of San Marcos, is a highly complicated zone of faulting characterized by numerous faults, some of which are of large throw. This zone of intense faulting trends north-northeast. The individual faults have in the main the same trend, although there are many faults of divergent trend, resulting in numerous small and irregularly shaped fault blocks, so that the fault pattern as a whole is very complex. To the north the two sub-zones of faulting in Hays County converge and unite at or near Colorado River in Travis County.

In Travis County north of Austin the faulting dies out rapidly and although, as may be seen in the section exposed on Walnut Creek, there are a great number of faults, the sum total displacement is greatly reduced. In Williamson County some faulting occurs on the line of continuation of this zone near Round Rock and Georgetown. Some faulting is present also several miles west of Georgetown. In Bell County the zone of faulting is seen in several faults east and northeast of Salado on Salado Creek and Lampasas and Little rivers. Some faulting occurs also near Belton.[55] In McLennan County some faults are seen in the vicinity of Waco.

In Hill County some faulting is reported between Whitney and Aquilla.[56] In all the region north of Travis County the faulting is so small that no pronounced scarp is present, and in north Texas the location of the Balcones zone is indefinite.

DESCRIPTION OF STRUCTURAL FEATURES

Summarizing the structural features of the Balcones zone, it is seen that the individual faults and folds and sub-zones of faulting do not as a rule exactly parallel the trend of the zone as a whole.

From Austin south each structural feature or sub-zone of faulting when followed southwestward is found to diverge to the east or south from the line of the zone as a whole; its individual faults, likewise, diverge from each other. The result is a scattering of the faulting until an escarpment is no longer apparent in the topography, and finally the sub-zone, passing out into the Gulf Coastal Plain, is entirely dissipated and can be followed no farther in a southwesterly direction. Illustrations of this behavior of the sub-zones of faulting are the following. At Austin heavy faulting is present near the west city limits. The course of Colorado River is controlled by this faulting from Mount Bonnell to the Austin dam.[57]

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[55]Adkins, W. S., and Arick, M. B., Geology of Bell County, Texas: Univ. Texas Bull. 3016, 92 pp., 1930.

[56]Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, p. 382, 1901.

[57]This dam, built 1890–93, proved ineffective on account of having been built across one of the large faults of the Balcones zone. It is said that no geologic advice was sought in locating the dam.

A pronounced escarpment, likewise, results from the faulting. The heavy faulting at Austin southward becomes two belts. The western belt, which passes near Oak Hill and may be designated as the Oak Hill belt, trends about S. 45° W. The other belt trends about S. 35° W. in the direction of Manchaca. The western belt of faulting forms the principal escarpment at Oak Hill in Travis County. The eastern belt located southwest of Kyle, which may be known as the Manchaca zone, develops numerous small scattered faults and terminates or possibly shifts to the east.

At San Marcos faulting is again concentrated to form a pronounced escarpment similar to that developed at Austin. Southward from San Marcos the faulting forms two sub-zones which diverge and at New Braunfels are 5 or 6 miles apart. The eastern sub-zone, passing through New Braunfels, forms the principal escarpment of Comal County and may be known as the New Braunfels sub-zone. The western sub-zone which continues to Bracken or beyond may be known as the Bracken sub-zone. In Bexar County the heavy faulting originating near Helotes and trending about S. 65° W., which may be designated as the Helotes sub-zone, forms the principal escarpment of that part of Bexar and Medina counties.

In Uvalde County the Uvalde Salient trends approximately north-south, and of its numerous accompanying faults of diverse trend some tend to parallel the salient. The Brackett anticline of Kinney County and accompanying faults trend northeast-southwest, while the zone as a whole in that county trends approximately east-west.

The resulting pattern is faults trending in the main tangent to the curved course of the Balcones structural zone where it curves around the Llano uplift. The explanation of this pattern is believed to be found in the fact that the fault trends are normal to the direction of tension, while the structural zone as a whole follows the curved course of the Llanoria geosyncline. Where the curve of the Llanoria geosyncline is in the opposite direction, that is, with concavity towards the sinking land mass, as in the region of Red River and the Rio Grande, faulting in this zone is less pronounced, and igneous flows are less likely to occur.

Pronounced escarpments resulting from faulting are found in the several sub-zones. Thus in central Travis County at Austin a pronounced escarpment occurs along the line of faulting resulting from a union of the Manchaca and Oak Hill sub-zones. Farther south at Oak Hill a pronounced escarpment is formed by the Oak Hill sub-zone, the Manchaca sub-zone forming no appreciable escarpment. At San Marcos a pronounced escarpment is formed by the united New Braunfels and Bracken sub-zones and at New Braunfels by the New Braunfels sub-zone alone. The most pronounced escarpment of Bexar County is formed by the Helotes sub-zone.

There is thus no one continuous escarpment since the pronounced escarpment resulting from faulting is in one sub-zone at one locality and in another at other localities, with intermediate regions in which there is no one pronounced escarpment. The term Balcones escarpment, therefore, refers to topographic features resulting from the pronounced change in the level of formations which occurs in crossing the Balcones structural zone and is not a single continuous equally developed escarpment making a definite boundary to the Gulf Coastal Plain.

Much new information is needed on localities where faulting is highly complicated and on the relation of cross faulting to the fault pattern as a whole. Folding is probably more distinctly characteristic of the Balcones zone than of the associated Mexia zone. Is compression necessary to form these folds. or do they form from the rebound of normal faulting? Progressive faulting in this zone through a long period of time is implied by the hypotheses here presented. Evidence of such progressive faulting and of faulting in successive periods of time will possibly accumulate as the zone is more closely studied.

The displacement in the faults of this zone varies from a few feet to 800 or 1000 feet. Displacement by combined dipping and faulting of as much as 1500 or 1700 feet is observed in the southwestern part of Bexar County within a distance of two miles across the Balcones zone (Univ. Texas Bull. 1932, p. 144). Some of the faults of small throw probably do not extend through the Cretaceous formations. That this is true of faults bounding small grabens may occasionally be seen in surface exposures. The large faults, on the other hand, are believed to affect the underlying pre-Cretaceous formations. In the northern part of Bexar County two wells, of which a record based on samples has been obtained, passed entirely through the Cretaceous formations and into older deposits. Of these two wells one is located on the Leon Springs Government Reservation, north of the principal fault of the Balcones zone at surface elevation 1156 feet. The other well is on the Camp Bullis Government Reservation, south of the first and largest fault of this zone at surface elevation 1050 feet. In the Leon Springs well the pre-Cretaceous was entered at about depth 1015 feet (+ 141) while in the Camp Bullis well these formations were entered at about depth 1790 feet (— 740). The difference in actual elevation between the top of the Paleozoic between the two wells is, therefore, 881 feet. As already stated, a surface fault of considerable displacement passes between the two wells. The distance between the two wells is about six miles, and a part of the difference of elevation of the top of the Paleozoic between the two wells is no doubt due to the southward slope of the Paleozoic floor. That a part, probably the larger part, is due also to the fault, trace of which is seen at the surface, is reasonably certain.

Faulting in the Balcones and Mexia zones was probably progressive through an extended period of time. It is not improbable that faulting may have been initiated along the Balcones zone in Mesozoic time accompanying deformation of the ancient peneplain at the time of the Cretaceous submergence. That faulting in this zone was progressive at some localities has been suggested by several geologists. Evidence of renewed faulting along the same plane in the Lytton Springs oil field has been given by Collingwood and Rettger.[58] Faulting of small throw is recognized in the Eocene formations at the surface in and immediately southwest of this field. The best recognized of these faults has a displacement at the surface estimated at somewhat less than 100 feet. Based on evidence obtained from wells, these authors determine the displacement by this fault in the Austin formation of the Upper Cretaceous age at 220 feet. Similar increase of displacement with depth is given by Collingwood[59] for the Yoast oil field in Bastrop County. A fault crossing the Yoast field, which in the Eocene formations has displacements of 300 feet, in the Austin formation has displacement of 500 feet. An increased thickness of the post-Austin Cretaceous

[58]Collingwood, D. M., and Rettger, R. E., The Lytton Springs oil field, Caldwell County, Texas. Bull. Amer. Assoc. Petr. Geol., vol. 10, p. 956, 1926.

[59]Collingwood, D. M., Magnetics and geology of Yoast field. Bastrop County, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 1196, 1930.

formations, Taylor and Navarro, on the downthrown side of the fault is cited as proof that the faulting occurred in post-Austin-pre-Taylor time.

That pronounced faulting in the Balcones zone has occurred in relatively recent time is shown by the newness of the topographic features produced by this faulting. The Balcones escarpment of Central Texas seemingly could scarcely have been in existence in its present form earlier than Pliocene time. That the Balcones zone is not entirely quiescent at the present time is shown by the fact that a small earthquake in this zone occurred in northeastern Texas and southeastern Oklahoma on April 11, 1934. This earthquake was perceptible over a narrow belt from Nevada in Hunt County, Texas, to Spencerville in Choctaw County, Oklahoma, a distance in a northeast-southwest direction of about 100 miles. The width of the belt in a northwest-southeast direction, on the other hand, at no place south of Paris exceeded 20 miles. Adjacent to Red River, however, the belt of appreciable jar widens to 30 or 40 miles. The great elongation in a northeast-southwest direction of this belt over which the earthquake was perceptible clearly indicates slip on a fault. The earthquake was recorded by seismographs at Austin, Little Rock, and St. Louis.

With regard to the Balcones structural zone, the following hypotheses are proposed:

1. The Balcones structural zone is located chiefly in and has a definite relationship to the Llanoria geosyncline.

2. The Paleozoic rocks of the Llanoria geosyncline, chiefly clastics, are less competent than are the rocks of the foreland, which include massive limestones; they are likewise less competent than are the rocks of the Llanoria land mass; accordingly, when the land mass subsided, the principal adjustment occurred in the geosyncline which acted as a hinge between the rigid foreland region and the subsiding land mass. It follows, therefore, that the Balcones zone originated because of the sinking of the Llanoria land mass and the formation of the Gulf of Mexico, and the faulting and folding have been progressive with that sinking through a part of Mesozoic and all or nearly all of Cenozoic time.

3. The faulting is normal because it results from a bending or slipping away of a gradually depressed land mass from a more rigid land mass.

4. The Llano uplift is a rigid eastward-projecting platform containing massive and not deeply covered limestones. Under these conditions there resulted pronounced faulting between the rigid platform and the depressed land area to the east.[60]

5. There is some reason for believing that the Llanoria geosyncline narrows as it circles around the present Llano uplift. If this is true the adjustment between the rigid foreland and the depressed Llanoria would be more narrowly confined, which would result in pronounced faulting around that region. The narrowing of the Coastal Plain and consequent increased rate of dip may likewise be a factor.

6. The trend of faults so formed tends to be normal to the direction of tension and slippage. The tension results from the depression of the Gulf of Mexico and the tilting of the intervening land mass which lies in a southeasterly direction; the faults accordingly in central Texas trend prevailingly northeast. As a result, the faults in the main are tangent in trend to the curved line of the structural zone around the Llano uplift. Faults with other trends are present including some cross faulting.

7. Conversely to the conditions of 4 and 5, where the belt of clastic sediments is broad, where the competent heavy limestones are deeply covered by overlying less competent strata, and where the belt is not curved, the adjustment is somewhat distributed, and the resulting structural condition is a monoclinal fold, or the required adjustment is taken up by small irregularly placed faults.

8. The slightly eroded condition of the fault scarps indicate that faulting in the Balcones zone was active in relatively recent time, Pliocene or later.

MEXIA ZONE OF FAULTING AND FOLDING

The Mexia structural zone is closely associated with the Balcones zone. The Balcones zone, however, is best developed from

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[60]The probable relation of Balcones faulting to the Gulf of Mexico and to the Llano uplift was commented on in 1923 by Pratt and Lahee (Bull. Amer. Assoc. Petr. Geol., vol. 7, pp. 226–236, 1923) and by Robinson (Econ. Geol., vol. 18, p. 727, 1923). Robinson also called attention to its relation to the zone of Ouachita thrusting.

Nueces River to Colorado River, while the Mexia zone is best developed from somewhat south of Colorado River through northeast Texas. The two zones are alike in that the faulting is by normal or gravity faults. They differ in that the downthrow in the Balcones zone is usually to the east or southeast while in the Mexia zone the downthrow is prevailingly to the west or northwest. Between the two zones there is thus a great down block or graben. The downthrow in the Balcones zone is not invariably to the east, since faults are present with throw to the west or northwest, producing small grabens. Likewise, in the Mexia zone the downthrow is not wholly to the west, since occasional faults are present with downthrow to the east or southeast. For the most part, the faults trend slightly oblique to the trend of the fault zones and approximately, but not exactly, with the strike of the strata. Folding is seemingly more pronounced in the Balcones zone than in the Mexia zone. In both zones, however, faulting in the hard rock strata becomes or tends to become folding in the softer strata.

The term Mexia fault zone seems to have been first used by Pratt and Lahee[61] in 1923, and was applied at that time to the faulting at Mexia with known extension as far southwest as Guadalupe River in Caldwell County. However, faulting at Mexia and its influence on accumulation of gas was recognized by Deussen[62] as early as 1914. Faulting near Tehuacana was mentioned by Hill[63] in 1900.

The Mexia zone is traceable almost entirely through Texas from near the Louisiana line in Titus County to Medina County or possibly to Maverick County. Associated with this faulting as with the Balcones faulting, are numerous igneous masses, found chiefly from Williamson to Medina counties.

In Maverick County, northeast of Eagle Pass, are some small faults which may represent the Mexia zone. These faults, which are of small displacement, trend northeast. They cut across the Chittim anticline which plunges southeast.

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[61]Pratt, W. E., and Lahee, F. H., Faulting and petroleum accumulation at Mexia, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 7, p. 229, 1923.

[62]Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Surv., Water-Supply Paper 335, p. 301, 1914.

[63]Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, p. 384, 1901.

The San Antonio structural feature of Bexar County, which continues southwest into Medina County, is essentially of the Mexia zone type since there is downthrow at the west side. In its northern part at least it has downthrow, likewise, at the east side. The Alta Vista structural feature, which apparently continues southwest, to the Somerset field in Atascosa County, likewise, has pronounced downthrow at the west side. The trend of the Alta Vista zone is in agreement neither with the strike of the formations, which swing westward, nor with the trend of the zone as a whole.

The width of the Mexia fault zone is well seen in Guadalupe and Caldwell counties. In this region are several sub-zones of faulting. From the westernmost of these sub-zones of faulting, which crosses San Marcos River near Staples, to the easternmost known large faulting near Luling is about 15 miles. Other faulting of this type may occur farther to the east or west of these faults. Detailed structural features in the Mexia zone have been described in reports on the many oil fields of this region.[64]

In addition to the Mexia zone there is more or less faulting throughout the Gulf Coastal Plain of Texas. Faults in the vicinity of Jacksonville in Cherokee County and near Mt. Enterprise in Rusk County merit a distinctive name which they seem not to have received and for which the term Jacksonville zone would be appropriate. In Rusk County these faults trend approximately east-west, but in Cherokee County the trend changes to southwest.

The following alternate hypotheses are entertained for the Mexia structural zone.

1. The downward tilting of the land mass towards the Gulf of Mexico resulted in the formation of grabens, and the Mexia zone is at the east margin of the largest of these grabens.

Against this hypothesis is the fact that the Mexia zone is best developed in north Texas where the Balcones is least developed. Moreover, the Mexia zone does not in all respects parallel the Balcones

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[64]Among publications relating to the Mexia zone cited in the bibliography and subject index of Vol. I are the following: Brucks, 164, 165, and 165a; Collingwood, 267a and 268; Collingwood and Rettger, 267; Deussen, 421; Fohs, 543 and 543a; Fohs and Robinson, 542; Foley, 544; Hill, Bauserman, and Carpenter, 728a; Hill, 803; Hull, 860; Lahee, 961, 963, 964, 965, 966, 967, and 969; Link, 999; McCollum, Cunningham, and Burford, 1076; Matson, 1060; Matson and Hopkins, 1062; Pepperberg, 1192a and 1193; Powers 1255; Pratt and Lahee, 1263; Robinson, 1326; Row, 1355; Sellards, 1412; Wrather, 1802.

zone but diverges from it in the northern part of the state and may also diverge from it in the southwestern part of the state. In the region of San Antonio the two zones are contiguous, or possibly the one in part cuts across the other.

2. The faulting is caused by the upward or vertical component resulting from the gulfward slip of a great mass of strata accompanying the formation of the Balcones faults. This is essentially the hypothesis of Pratt and Lahee.[65]

Against this hypothesis is the fact already stated that the Mexia type of faulting is greatest in northeast Texas where the Balcones faulting is least. This objection may be answered in part by the fact that gulfward creep, such as might result in a vertical component, does not necessarily express itself in extensive faulting but possibly by distributed faulting or other adjustment.

3. The location of the Mexia fault zone is at the gulfward edge of the Llanoria geosyncline, the faulting being determined by the different competency of the rock of the Llanoria land mass and of the bordering geosyncline. This hypothesis has been proposed by Miser.[66]

Against this hypothesis is the fact that the Mexia zone may, and at some localities does, include several approximately parallel faults. If the westernmost fault, as in Caldwell County, is at or near the margin of the geosyncline, as seems possible from the available well records, the other faults to the southeast are necessarily some miles east of the geosyncline. Moreover, faults occur more or less throughout the Coastal Plain at the west and northwest sides of the Gulf of Mexico, some with downthrow to the west or north and some with downthrow to the east or south. Obviously not all of these faults can be accounted for as related to the Llanoria geosyncline.

The three hypotheses are not necessarily conflicting. Tilting to the east would probably form grabens, and, if so, the faulting at the downdip side of a graben so formed would be of the Mexia type. A slipping gulfwards of a large mass of the Coastal Plain sediment, whether by conspicuous faulting or by inconspicuous creep, might very probably result in buckling and upwards reaction farther out

[65]*Op. cit.*, p. 230.

[66]Miser, H. D., Paper read at the Houston meeting of the American Association of Petroleum Geologists, March, 1933.

in the basin as stated by Pratt and Lahee. Under these conditions the place of major buckling or major formation of graben may be at the margin of the geosyncline as hypothecated by Miser. A point in favor of the third hypothesis is the seeming convergence of the Mexia and Balcones zones in the San Antonio region where the geosyncline is assumed, for other reasons, to have been narrow. Unfortunately the actual gulfward margin of the Llanoria geosyncline is undetermined except on the most meager evidence. Hence, the Miser hypothesis will be difficult to prove or disprove.

SALT DOMES[67]

The salt domes of the Gulf Coastal Plain are remarkable structural features consisting of upthrusts of salt rising often many thousands of feet from a source, the geologic position and age of which are unknown. The domes rise mostly from the deep basins. This fact is probably not to be taken as indicating that the parent salt deposit is present only in the basins. The salt strata are doubtless much more widely distributed than are the domes. The concentration of the domes near the center of the basins is probably due to the fact that the pressure of the overlying sediments is there greatest and that this pressure is the force causing the upthrust of the salt.

The approximate distribution of the salt domes of the Texas Gulf Coastal Plain is indicated in Plate I. It is not practicable, however, to indicate all known salt domes of the region on a map of this scale, and the map should be used only to indicate the areas of salt dome distribution. By the use of geophysical methods many salt domes have been discovered in recent years and many more doubtless remain to be discovered. No salt domes have been found in the line of the coastward extension of the broad Concho arch, and this arch, or old positive element, may in fact divide the salt domes of the Rio Grande region from those farther east. Likewise, no salt domes have been found on the Sabine uplift, although domes are present in the not greatly depressed basin which separates this uplift from the Monroe uplift in Louisiana.

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[67]The publications on the salt domes of the Texas region are numerous. Those interested should consult Geology of Salt Dome Oil Fields, by E. DeGolyer and others: Amer. Assoc. Petr. Geol., 1926. Among many other publications on salt domes cited in the bibliography of Texas geology, Vol. I, are the following: Barton, 65 and 69; Cheney, 244; Clapp, 250; DeGolyer, 401a, 405, and 406a; Fenneman, 537; Harris, 668; Heath, Waters, and Ferguson, 696; Judson, 898; Lahee, 968; Owens, 1167a; Powers and Hopkins, 1250; Pratt, 1261 and 1270; Renick, 1298; Rogers, 1344; Schmidt, 1372b; Sellards, 1427; Wendlandt and Knebel, 1728.

The mechanics of salt domes have been recently very fully discussed by Barton.[68] The view that salt domes are formed by the flowage of salt under pressure is now very generally accepted. The motivating force may be entirely pressure arising from the overlying sediments, flowage of salt occurring on such lines of reduced resistance as may exist. Tangential pressure has also been proposed as a motivating force in salt flowage.

A fluid mechanical hypothesis for the formation of salt domes was presented by L. L. Nettleton at the Dallas meeting of the American Association of Petroleum Geologists, March, 1934. The basic assumptions of this hypothesis are (1) that the prime motive force for the formation of domes is the density difference between the salt and the surrounding sediments, and (2) that both the salt and the surrounding sediments behave as highly viscous liquids and slowly flow through long geologic time.

The following statements are from the abstract which accompanied Mr. Nettleton's paper.

> A simple analysis of the behavior to be expected under the assumptions shows that a "peripheral sink" will be formed. This will cut off the supply of salt flowing into the dome but this cut-off does not depend on the salt being actually pinched off by the meeting of rocks originally above and below the salt. It may occur at any stage in the development of the peripheral sink, depending on the strength or viscosity of the overburden.
>
> A series of qualitative experiments shows the flow, under a wide range of relative viscosities, of two liquids of different densities with the lighter liquid originally below the heavier liquid. The experiments illustrate the modifications of the flow produced by the peripheral sink and the manner in which the cut-off by the peripheral sink is controlled by the relative viscosities of the two liquids involved.

Under this hypothesis the conditions initiating and determining the location of a salt dome are such structural deformation as may exist in the salt and overlying sediments. The effect of structural deformation, even when the deformation is mild, is to set up a difference in the weight of the column of sediments above the uplift as compared to the weight of the sediments adjacent to the uplifted or upwarped structural feature. This difference in weight brings about, under this hypothesis, the differential pressures necessary to initiate the formation of a salt dome. This theory of the initiation

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[68]Barton, D. C., Mechanics of formation of salt domes with special reference to Gulf Coast salt domes of Texas and Louisiana: Bull. Amer. Assoc. Petr. Geol., vol. 17, pp. 1025–1083, 1933.

of salt domes helps to account for the observed alignment of these domes in some localities. It is elsewhere shown in this volume that prevailing structural trends in Texas are northeast-southwest, and northwest-southeast. The northwest-southeast alignment of certain domes in Louisiana is well known, and there is an obvious northeast-southwest alignment in some of the domes of the Texas region.

It has been shown that the growth of some of the salt domes has been progressive. It has been shown, also, that some of them have continued growth into very recent time. Some are doubtless still growing, although the rate of growth is slow. Barton states that several of the domes of the Gulf Coastal region can be shown to have grown in post-Pliocene time. On the other hand, some ceased growth in much earlier time.

Determination of the geologic age in which the domes first began to grow is much more difficult. That upthrusting of salt occurred throughout the Cenozoic time is very well demonstrated. To what extent there may have been growth of salt domes during Cretaceous time is undetermined.

The age of the salt of the salt domes is one of the unsolved problems of Coastal Plain geology. In the Smackover oil field of Arkansas salt has been found to underlie very early Cretaceous deposits.[69] The salt of this region, therefore, is either earliest Cretaceous or is pre-Cretaceous. In the northeast Texas syncline, formations as old as the Glen Rose, Lower Cretaceous, have been lifted up with the salt indicating that the mother salt lies below that level.[70] In the Gulf Coast region the oldest formation known to have been brought up by the salt is of the Navarro formation, Upper Cretaceous. It appears, therefore, that the salt of all of the domes is Cretaceous or older. Whether the salt of all of the domes is of the same age or whether salt beds of different ages are involved is likewise unknown.

The salt domes afford reservoirs of great value for several minerals and mineral products. In addition to minerals brought up in these upthrusts of salt, there are others, as oil and gas, that find in the resulting structural features favorable storage conditions

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[69]Spooner, W. C., *op. cit.*; Bell, H. W., *op. cit.*

[70]McLellan, H. J., Wendlandt, E. A., and Murchison. E. A., Boggy Creek salt dome, Anderson and Cherokee counties, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 16, pp. 584–600, 1932

in which accumulation in commercial quantities is possible. Anhydrite occurs in the salt domes either as thin strata or as impurities amounting to a few per cent disseminated through the salt. By concentration incident to solution of the salt, residual anhydrite often accumulates to form a thick stratum at the top of the salt mass. The anhydrite by alteration processes may, and often does in part, change to gypsum. Salt is the one mineral that is brought up in the salt domes in great quantities. As previously stated, the salt under the pressure of overlying sediments finds a place of least resistance and flows, or is bodily thrust upwards. In the completed dome there is thus a stock or core of salt which may reach downwards to a connection with the parent salt bed at a depth of many thousand feet. A limestone stratum of secondary origin is present capping many of the domes. Another mineral of great value found in some of the domes is sulphur. This mineral, likewise, is of secondary origin and is contained in the limestone caprock of the dome.

The limestone caprock of salt domes forms an excellent storage reservoir for oil and gas, and some of the domes have produced extensively from this stratum. In addition, the upthrusting of the stock of salt results in the formation of reservoirs suitable for the storage of oil and gas at the sides of the domes from which a very large oil production is being obtained. Among other minerals that have been found in the salt domes, occurring usually in small quantities are the following: barite, barium sulphate ($BaSO_4$);[71] galena, lead sulphide (PbS);[72] hauerite, manganese sulphide (MnS_2);[73] sphalerite, zinc sulphide (ZnS);[72] sylvite, potassium chloride (KCl);[74] potassium mineral (not determined).[75] For a publication on the economic importance of salt domes see University of Texas Bulletin 2801.[76]

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[71]Hanna, Marcus A., Secondary salt dome materials of Coastal Plain of Texas and Louisiana: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 1469, 1930.

[72]Hanna, Marcus A., Galena and sphalerite in the Fayette at Orchard salt dome, Fort Bend County, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 13, p. 384, 1929.

[73]Wolf, Albert G., Haurite in a salt dome cap rock: Bull. Amer. Assoc. Petr. Geol., vol. 10, p. 531, 1926.

[74]DeGolyer, E. L., Discovery of potash salts and fossil algae in Texas salt dome: Bull. Amer. Assoc. Petr. Geol., vol. 9, p. 348, 1925.

[75]Wendlandt, E. A., and Knebel, G. M., Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Bull. Amer. Assoc. Petr. Geol., vol. 13, p. 1369, 1929.

[76]Barton, D. C., The economic importance of salt domes: Univ. Texas Bull. 2801, pp. 7–53, 1928.

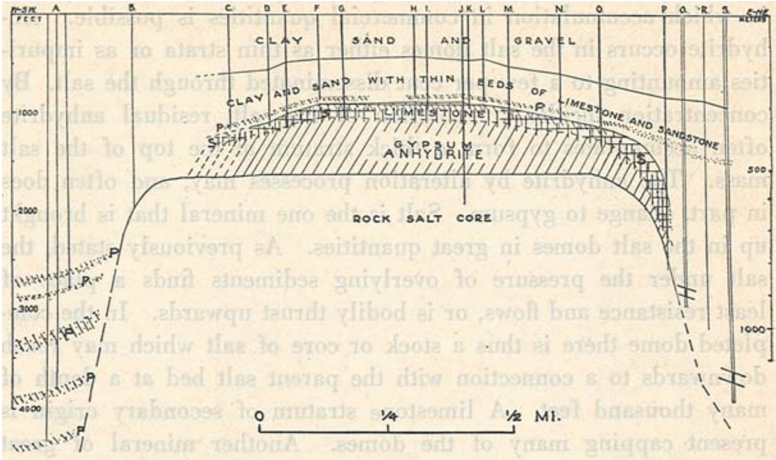

Fig. 5. Diagrammatic section of a Texas-Louisiana salt dome showing its structural features as a storage reservoir for salt, anhydrite, gypsum, sulphur, limestone, oil, and gas. Presence of oil, gas, and sulphur indicated by shading as follows: oil and gas (P) by oblique lines in and above the cap rock and at the sides and sulphur (S) by vertical lines in the cap rock. Modified after Barton from University of Texas Bulletin 2801.

Following is a list of salt domes in Texas as known at the present time. Domes have been discovered rapidly in late years and the total number of domes known is being increased from time to time. Some of the domes here mentioned are more or less doubtful and are so indicated (groups II and III). Others, in which wells have been drilled either to the cap rock or to the salt, are definitely known to be domes (group I). The approximate location of the domes is indicated insofar as practicable on the structural map, Plate I (in pocket). In arranging this list the writer is indebted to information given by D. C. Barton, M. A. Hanna, J. C. Miller, and E. A. Wendlandt.

LIST OF SALT DOMES IN TEXAS

Group I

Proven salt domes in which the cap rock or salt or both have been reached in drilling.

Anderson County
1. Bethel
2. Boggy Creek (Extends into Cherokee Co.)
3. Brushy Creek
4. Keechi
5. Palestine

Austin County
6. Brenham (Extends into Washington Co.)
7. San Felipe (Sealy; Brookshire) (Extends into Waller Co.)

Brazoria County
8. Allen

9. Bryan Heights
10. Clemens
11. Damon Mound
12. Danbury
13. Hoskins Mound
14. Nash (Extends into Fort Bend Co.)
15. Stratton Ridge
16. West Columbia

Brooks County
17. Gyp Hill (Falfurrias; Loma Blanca)

Chambers County
18. Barbers Hill
18a. Hankamer (Extends into Liberty Co.)
19. Lost Lake
20. Moss Bluff (Extends into Liberty Co.)

Cherokee County, see Anderson County

Duval County
21. Palangana
22. Piedras Pintas

Fort Bend County
23. Big Creek
24. Blue Ridge
25. Boling (Extends into Wharton Co.)
26. Long Point
14. Nash (Extends into Brazoria Co.)
27. Orchard (Moore; Moores Field; Moores Dome)
28. Sugarland (DeWalt)

Freestone County
29. Butler
30. Oakwood (Extends into Leon Co.)

Galveston County
31. High Island

Grimes County
32. Ferguson Crossing

Hardin County
33. Ariola
34. Batson
35. Saratoga
36. Sour Lake

Harris County
37. Hockley
38. Humble
39. Pierce Junction

Henderson County
40. LaRue

Houston County
40a. Kittrell (Trinity) (Extends into Walker Co.)

Jefferson County
41. Big Hill
42. Fannett
43. Spindletop

Leon County, see Freestone County

Liberty County
44. Davis Hill
45. Esperson
18a. Hankamer (Extends into Chambers Co.)
46. Hull
20. Moss Bluff (Extends into Chambers Co.)
47. North Dayton (Dayton)
48. South Liberty (Liberty; South Dayton)

Matagorda County
49. Gulf (Big Hill)
50. Hawkinsville
51. Markham

Orange County
52. Port Neches (Mansfield Ferry)

Smith County
53. Brooks
54. Bullard
55. East Tyler
56. Mount Sylvan
57. Stein (Steen)
59. Whitehouse

Van Zandt County
60. Grand Saline

Walker County, see Houston County

Waller County, see Austin County

Washington County
6. Brenham (Extends into Austin Co.)
61. Clay Creek (Gay Hill)

Wharton County, see Fort Bend County

Wood County
62. Hainesville

Group II

Domes not proven by drilling into either cap rock or salt but considered from geological and geophysical evidence as probably salt domes.

Austin County
63. Raccoon Bend (Ives Creek; Cochran Crossing) (Extends into Waller Co.)

Brazoria County
63a. Hastings (Friendswood)
64. Manvel

Brooks County
65. Palo Blanco

Chambers County
66. Anahuac

Fort Bend County
67. Thompsons (Rabb Ridge; Clear Lake)

Galveston County
68. Dickinson

Harris County
70. Genoa
71. Goose Creek
72. Mykawa
73. South Houston
74. Tomball (Extends into Montgomery Co.)

Jefferson County
75. Nome (China)

Leon County
76. Marquez

Liberty County
77. Cleveland
77a. Hardin

Matagorda County
78. Bay City (Van Vleck)
79. Shepherds Mott

Montgomery County
80. Conroe
80a. Splendora
74. Tomball (Extends into Harris Co.)

Orange County
81. Orange (Cow Bayou; Terry)

Polk County
82. Ace
83. Livingston

Waller County
84. Katy
63. Raccoon Bend (Ives Creek; Cochran Crossing) (Extends into Austin Co.)

Group III

Structural features in which the evidence for the presence of salt is less definite than in Group II.

Anderson County
85. Camp Hill
86. Cayuga
87. Long Lake

Brazoria County
88. Old Ocean
89. Pledger (Extends into Matagorda Co.)
90. Rattlesnake Mound

Brooks County
91. Alta Verde

Colorado County
92. Garwood

Duval County
93. Driscoll

Freestone County
94. Red Lake

Harris County
95. Eureka

Leon County
97. Buffalo

Matagorda County
98. Buckeye
99. Citrus Grove
89. Pledger (Extends into Brazoria Co.)

Montgomery County
100. Willis

Tyler County
100a. Spurger

Van Zandt County
101. Van

Wharton County
102. Louise
103. Pickett Ridge

SUMMARY OF TEXAS GULF COASTAL PLAIN STRUCTURAL FEATURES

Pre-Cambrian folds in the Llano region, revived in Upper Pennsylvanian time, may be directly connected with the San Marcos arch of the Coastal Plain. At either side of this arch and the Llano uplift are deep indentations of Coastal Plain deposits indicating structurally low areas. Of these, the Rio Grande embayment may have been present since late Jurassic or early Cretaceous time. The Northeast Texas embayment, originating possibly equally early and affected by the modifying influence of the Sabine uplift and possibly other Coastal Plain structural features, continued as an embayment until Oligocene time. The salt domes of the Gulf Coastal Plain have formed through Cenozoic time.

CENTRAL TEXAS

The term Central Texas is here used to apply to that part of the state west of the Gulf Coastal Plain, east of Pecos River, and east of the High Plains. Its principal subdivisions are Llano, Edwards Plateau, Grand Prairie, and Osage Plains regions (fig. 3, p. 32). Although these subdivisions, with the exception of the Llano region or uplift, are geographic rather than structural they, nevertheless, form convenient headings under which to describe structural features.

LLANO REGION[77]

The Llano region or Llano uplift is structurally a large dome located in Central Texas. The formations exposed in the center of the dome are of pre-Cambrian age, these older rocks being surrounded by formations of Paleozoic and Cretaceous age. The structural history of this region includes deformation antedating the Upper Cambrian, doming in Paleozoic time, and faulting in or preceding Strawn time. In addition to the structural deformation of these periods the region has undergone repeated fluctuations in elevation in Paleozoic and Mesozoic time as shown by the several incursions of the sea across this region.

PRE-CAMBRIAN DEFORMATION

The pre-Cambrian sedimentary rocks of this region are somewhat altered and usually greatly deformed. There is, however, no evidence that the deformation seen in the pre-Cambrian rocks is confined to or otherwise characteristic of this particular region. On the contrary, it is probable that pre-Cambrian deformation of the kind here seen is widespread and is found in the pre-Cambrian elsewhere in this part of the state. This conclusion is supported by the fact that wherever the drill has penetrated to pre-Cambrian formations in Central Texas these formations have been found to consist of rocks similar in degree of alteration to those of the Llano region. Within the pre-Cambrian is seen a northwest-southeast structural trend developed in pre-Cambrian time. The following statement on

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[77]Among publications relating to structural conditions in the Llano uplift cited in the bibliography and subject index of Vol. I are the following: Comstock, 271 and 274; Dake and Bridge, 386b; Hill, 743; Paige, 1170, 1171, 1172, and 1173; Powers, 1254; Sellards, 1403; Stenzel, 1525c; Ulrich, 1674b; Walcott, 1702; Willis, 1761c.

pre-Cambrian structural conditions in this region has been kindly supplied by Dr. H. B. Stenzel.

PRE-CAMBRIAN STRUCTURAL CONDITIONS IN THE LLANO REGION

H. B. Stenzel

The pre-Cambrian of the Llano uplift should be subdivided into three series from the point of view of structure. These series in order, No. I being the oldest, are as follows:

III. Late dike intrusions, comprising the opaline quartz-porphyry and felsites.
II. Batholithic intrusions, comprising the various granites and their aplite and pegmatite dikes.
I. Folded frame metamorphic rocks, comprising the schists, including marbles and gneisses.

Each series has its own characteristic features ranging from the large scale tectonics down to the minute scale petrographic textures.

The schists and gneisses form the containing walls of all later intrusions. They are the framework of the whole. Valley Spring gneiss and Packsaddle schists[78] are strictly conformable in all outcrops and folded as one unit; their average strike is northwest-southeast; their average dip is steep, around 45°. Bedding and schistosity are parallel. The grain in schists and gneiss is parallel to the pitching axes of the open folds. The rocks of the folded frame are thrown into wide, open folds that trend northwest-southeast and pitch near Llano at an average angle of 16° to the southeast. Sidney Paige shows three such anticlines and synclines between Llano and Burnet. The open folds are by no means very regular and are somewhat complicated by cross-flexures. The cores of anticlines are occupied by gneiss mainly; the centers of synclines are occupied by schists mainly. Therefore, it could be stated that the schists overlie the gneiss and are younger. This is, in my opinion, not the case. There are many gneiss sills in the schists and many schist lenses in the gneiss. The gneiss is intrusive in the schists in such a manner as to conform very strictly to the planes of schistosity of the Packsaddle schists. The gneiss sills increase in number and size as one goes from the center of a syncline to the core of an anticline so that ultimately gneiss predominates and composes the very foundation of the region. Such arrangement can be explained best by the assumption that the intrusion of the gneiss took place during the folding and metamorphism of the schists and that the metamorphism of the schists was aided by the gneiss intrusion.

Isoclinal and zigzag folds are also present in this region. Here and there knees of such folds have been found, but, of course, they are found only in

[78]The terms Valley Spring gneiss and Packsaddle schists are used here in a somewhat different sense to that in which they were used by Sidney Paige. The Valley Spring is restricted to include only the very uniform orthogneiss of the region excluding all rocks of sedimentary derivation. The Packsaddle schists include all schists and associated rocks that are of sedimentary derivation.

rare, exceptionally good exposures. That these folds are much more common than one would suppose from a superficial study is shown by the numerous repetitions of marble bands in the schists. For instance, east of Oxford there are at least seventeen marble layers in the schists. They do not represent layers of different original stratigraphic position but rather layers repeated by closely appressed isoclinal folding.

The batholithic intrusions are very numerous and are wedged between the rocks of the folded frame. The granites have been divided into three groups by Stenzel:[79]

III. Sixmile granites; fine-grained, gray biotite granites, typically exposed in quarries near Sixmile.

II. Oatman granites; medium-grained, gray to pink, cataclastic granites, typically exposed in Oatman Creek southeast of Llano.

I. Town Mountain granites; coarse-grained to porphyritic granites, commonly with large flesh-colored feldspars, typically exposed in the abandoned quarries on Town Mountain north of Llano.

Each of these granite groups has its own dike systems of aplites and pegmatites. Lamprophyres are absent. The difference in age between some of the granite groups is considerable. Thus, in the Cassady quarries near Sixmile there are exposures showing inclusions of Town Mountain granite in Sixmile granite. The inclusions are angular, and even the aplites that cross and belong to the Town Mountain granite are cut off sharply by the Sixmile granite. The Town Mountain granite and its aplite must have been fully solidified before intrusion of the Sixmile granite so that they could be broken into angular fragments.

The largest intrusive bodies are formed by the Town Mountain granites, as for instance the following:

a. Midway sill, exposed north of the Burnet-Llano road for 3.25 miles, located about 7 miles northwest of Burnet.

b. Lone Grove body, extending from Lone Grove to east of Bluffton (12 miles) and from the Cambrian in the north to the schist-band that strikes from Graphite to the base of Long Mountain.

c. Wolf Mountain body, exposed between Town Mountain and Wolf Mountain, 1 and 8 miles northwest of Llano respectively.

d. Granite Mountain body, exposed northwest of Marble Falls for a width of about 10 miles.

e. Enchanted Rock body, reaching from near Castell in the north to beyond the Enchanted Rock. It is about 10 miles wide and more than 14 miles long.

These bodies have much in common. The grain size of the granites is large in the centers but decreases very much to the margins and is only medium in the outlying offshoots. Color changes from red or flesh-mottled in the centers

[79]Stenzel, H. B., Pre-Cambrian of the Llano uplift, Texas (abst.): Bull. Geol. Soc. Amer., vol. 43, pp. 143–144, 1932.

of the bodies to gray at the margins. Flow structure is noticeable everywhere; the margins especially have very strongly developed "schistose" flow structure. Contacts are chiefly concordant, although cross-cutting offshoots may be found in most exposures. Along the contacts there are many lenticular sills of granite in the country rock and long narrow inclusions of country rock in the

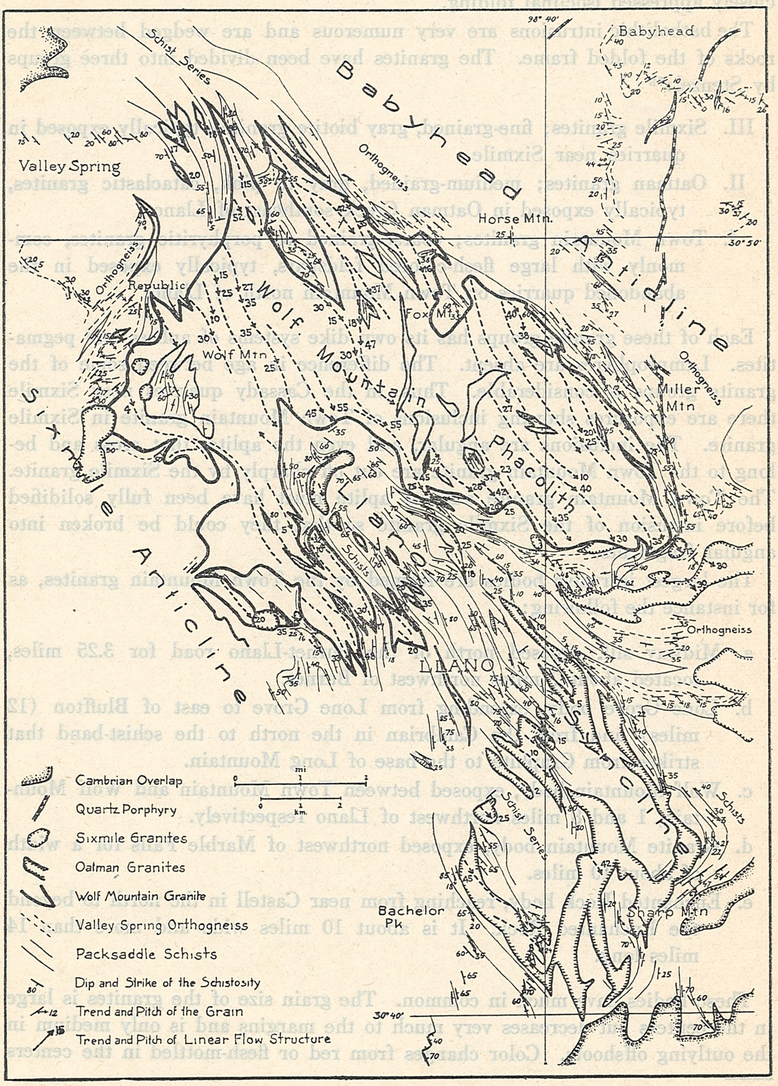

Fig. 6. Map of structural features in the pre-Cambrian rocks in the vicinity of Llano, Texas, by H. B. Stenzel.

granite. The contacts are more or less wide zones of interfingering between granite sills and country rock. Flow structure parallels the contacts and is of the plane type. Good exposures of contacts may be seen on the Llano-Burnet road at the east end of Lone Grove and east of the creek at Enchanted Rock. Nearer to the center of these intrusive bodies inclusions of country rock become less common, but they never seem to be absent. The inclusions have usually a flat, paddle-like shape and are nicely aligned with the flow structure of the igneous matrix.

The individual shape of these Town Mountain intrusive bodies is difficult to understand, and it is necessary to map the entire body and to observe the contacts. The simplest body in this group is the Midway sill in Burnet County. It is about a quarter of a mile thick and exposed for a length of 3.25 miles; both ends are covered by Cambrian sediments. To the north it is bounded by gneiss; to the south by schists chiefly. Schists, gneiss, sill, and its plane flow structure strike at an average N. 70° W. and dip at an average 46° S. The gneiss underlies the granite. Obviously the gneiss-schist boundary offered an easy path for intrusion. This holds true for all Town Mountain granites that have been investigated. Their place of intrusion is the gneiss-schist boundary. Pegmatites are quite common in the Midway sill; thirty-six were encountered. Their average strike is N. 73° W. and dip is 37° N. This is very nearly at right angles to the combined average of plane flow structure and inclusions in the sill. The average strike of these is N. 64° W. and dip is 44° S. This shows that the pegmatites are intruded along a master joint set (Q-joints of H. Cloos) and that, during and after the intrusion of the sill, the greatest compressive stress was at right angles to the walls of the sill while the least stress was parallel with the walls and at right angles to the pegmatites.

Of great interest is the Wolf Mountain intrusive body. Its outcrop is roughly an inverted U that is open to the southeast. To the outside of this inverted U, in the northeast, northwest, and southwest, there is chiefly gneiss, while to the inside enclosed by the granite on three sides there are schists. These schists form the down-plunging and roughly U-shaped end of a syncline. This body is located in a synclinal trough between the gneiss and the schists. Contacts on the outside of the U, that this body outlines, dip under the granite; on the inside of the U they dip away from the granite under the schists. This body is a phacolith intruded along the gneiss-schist boundary in the trough of a syncline that plunges 16° southeast.

Flow structure in this mass is of two types, plane and linear. The plane flow structure is noticed best along the contacts and parallels the contact walls. The linear flow structure is more uniformly distributed in the phacolith. Many small spindle-shaped schist inclusions are aligned with it by their longest axes. This linear flow structure trends northwest-southeast and pitches to the southeast a little steeper than the axis of the syncline in which the phacolith lies. Pegmatite and aplite dikes are very numerous. Some of the aplite dikes attain very large proportions. Usually they cut at about right angles through the linear flow structure. Therefore, the majority of the dikes strike northeast-southwest and dip to the northwest in this body. Flow structure and dikes in the phacolith indicate that the greatest compressive stress was in northeast-southwest (or opposite) direction; least stress was in the direction of linear flow structure. As a whole, indicated stress conditions in the granite were identical with the stress conditions indicated by the open folds of the gneiss and schists in which the granite intruded. This apparently means that the granite was intruded under tectonic pressures similar to the pressures that produced the folds in the folded frame, or, in other words, the phacolith was intruded at the end of the period of folding of the frame.

An interesting problem presents itself in the question of location of the feeding channel for the phacolith. Did the granite magma rise along the pitching keel of the syncline or did it rise along other channels? The phacolith is not very symmetrical. Of the two branches of the U the northeast branch is over three times as wide as the southwest branch. If the size has anything to do with proximity to feeding channels, the channel should be in the northeast. Along the outer northeast contact of the phacolith there is a zone of crumpled gneisses and schists. The zone is exposed in many places from Pecan Creek west-northwest of Horse Mountain to a left tributary of Mitchell Creek southwest of Miller Mountain for a length of 5.5 miles at least. It is about 100 to 500 feet from the granite contact. In this zone the crumpled schists or gneiss are welded together by tortuous granite stringers but pegmatites cut straight through stringers and all. The crumpling, therefore, was older than or contemporaneous with the granite intrusion. The crumpling in this narrow shear zone was produced by a shear of northwest-southeast trend in which the northeast block moved to the southeast. In the continuation of the shear zone to the northwest, the phacolith has its greatest length and ends in two long narrow tips that are accompanied by several larger sills of the same granite. These sills contain large grained granite. while sills in the south end of the phacolith west of Llano have much finer grain. All these features make it very probable that the feeding channel of this body is near this shear zone along the northeast contact.

The Oatman granites form elongate outcrops southeast and northwest of Llano. The arrangement is *en échelon.* The details of the contacts of these bodies are very irregular, the granites erratically cross-cutting at the contacts. Yet the general alignment of the bodies is with the strike of the schists. Near Llano the trend of the bodies is northwest-southeast, but in the vicinity of Sharp Mountain the schists and with them the granites make a right angle turn and strike northeast-southwest and dip to the southeast. The fiber of the schists continues in the old direction, northwest-southeast trend with southeast pitch. I believe the Oatman granites to be intruded along strike faults or strike fractures. These are possibly produced by a shear motion not unlike the *en échelon* faults of Oklahoma according to A. E. Fath.[80] If this be the case, the shear would be corresponding to the shear in the crumpled zone of the Wolf Mountain phacolith, the northeast block moving relatively to the southeast.

The Sixmile granites were not investigated in detail because exposures of contacts did not seem to be abundant.

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[80]Fath, A. E., The origin of the faults, anticlines, and buried "Granite Ridge" of the northern part of the Mid-Continent oil and gas field: U. S. Geol. Surv., Prof. Paper 128-C, pp. 75–84, 1920.

The last igneous activity in the region is represented by the opaline quartz-porphyry and its allies. These late dike intrusions have a flow structure that is parallel to the walls. The walls were rigid during their intrusion. The dikes lie in a prominent fracture system of north-south direction that seems to foreshadow some of the later Paleozoic north-south faults.

PALEOZOIC DEFORMATION

The earliest Paleozoic event recorded in the Llano region is the incursion of the Upper Cambrian sea. This sea transgressed across a land of some appreciable topographic relief, granite knobs, in particular, rising above the general land level. In this respect the Llano region probably differed in no way from the surrounding region. The pre-Cambrian folds had been truncated, and topographic highs did not coincide with structural highs. There is, in fact, no evidence that the Llano uplift as such existed at that time. At any rate, the Upper Cambrian sea transgressed entirely across the present uplift. During Upper Cambrian and Lower Ordovician time this region underwent changes in level, resulting in erosion, disconformities, and overlaps. In parts of the region examined by Dake and Bridge[81] the overlap was found to be progressively westward, but whether or not this condition holds for the region as a whole or for a larger part of the state is undetermined.

The Upper Cambrian-Lower Ordovician sediments as a whole present appreciable variation in thickness, in general thinning westward. The following records from wells show the thickness of the Cambrian and Ordovician at the localities indicated. Since an erosional unconformity is present at the top of the Lower Ordovician, the actual full thickness of the early Paleozoic formations is, of course, not present. At a few localities where wells were drilled, the early Paleozoic was found to be immediately overlain by formations later in age than the Bend and at some of these localities the Ellenburger and much of the Cambrian had been removed by erosion previous to the deposition of the overlying post-Bend formations. However, in the following list there are given only those wells in which the Ordovician is overlain by Mississippian or Lower Pennsylvanian (Bend), or (in Reagan and Crockett counties) by Middle

[81]Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas (with appendix by E. O. Ulrich, pp. 742–747): Bull. Geol. Soc. Amer., vol. 43, pp. 725–741, 1932.

Ordovician. Several wells are included which, although terminating in Ordovician or Cambrian, nevertheless penetrated to such depth as to give an important check on thickness.

List of wells used in determining thickness of the Upper Cambrian and Lower Ordovician in Central Texas

The abbreviations used are as follows: TD, total depth; Ord, Lower Ordovician; Camb, Cambrian; p-Camb, pre-Cambrian; Thick, thickness of Upper Cambrian and Lower Ordovician combined; and Th-El, thickness of Ellenburger. The plus sign indicates that the full thickness was not shown by the well; the star (*) indicates that the formation referred to was not reached.

Name and location of well	TD	Ord	Camb	p-Camb	Thick	Th-El
Brown County: Cross 1, A. A. Peard; E. D. Prewett Surv. 13; south county line	2803	1270	2470?	*	1533+	1200
Brown County: Fuller 1, Empire Oil and Gas Co.; C. B. Jenning Surv. 553; 2¼ mi. W, 1¼ N Bangs	3708	2345	3203?	*	1363+	858
Brown County: Smith 1, McDaniel et al.; J.F. Crawford Surv.; 4 mi. S Zephyr	3434	1487	2870?	3391±	1904	1383
Crockett County: Todd 1, Stanolind Oil and Gas Co.; G.C.&S. F.Ry.Co. Surv., Bl. UV, Sec. 67; 8 mi. W, 4 N Ozona	8042	7247	*	*	795+	795+
Eastland County: Davis 1, S. A. Hopkins et al; H.&T.C.Ry.Co. Surv., Bl. 4, Sec. 54; 1.7 mi. from N, 11.9 from W county line	5646	3930	4926	5425±	1495	996
Fisher County: George 1, Cranfill and Reynolds; B.B.B.&C. Ry.Co. Surv., Bl. 1, Sec. 200; 5 mi. from E, 6 from N county line	6494	6175	*	*	319+	319+
Kimble County: Hodges 1, Mudge Oil Co.; G. Kimble Surv., Sec. 27; 6 mi. NE Junction	2902	1635	2441?	*	1267+	806
Lampasas County: Whittenburg 1, Western Lampasas Oil Co.; John Boyd Surv. 612, Bl. 229, Sec. 38; 3 mi. W Lometa	4180	979	2976	3580	2601	1997
McCulloch County: Beasley 1, Dallas Milburn Valley Oil Co.; F. Winkle Surv.; 2½ mi. N, 2½ E Mercury	2526	945	1896?	*	1581+	951
McCulloch County: Baumgartner 1, Texas Hurst Syndicate; P. H. Schaff Surv. 402; 1½ mi. SSE Brady	1384	61	910?	*	1323+	849

Name and location of well	TD	Ord	Camb	p-Camb	Thick	Th-El
McCulloch County: Brady water well; Brady	2114	187	980	*	1927+	793
McCulloch County; C.A. Wyer 1, Burford and Brimm; D. Mechels Surv. 968; 3 mi. SE Mercury	2130	685	1486?	2100?	1415	801
McCulloch County: Craig 1, Thomas et al; C. Usner Surv., Sec. 1351; 4½ mi. N, 1 W Melvin	3666	2065	2625?	3473?	1408	560?
McCulloch County: Crews 1, Southwestern Petroleum Co.; U. Heinrich Surv., Sec. 782; 1 mi. SW Rochelle	1965	605	1435?	*	1360+	830?
McCulloch County: Dutton 1, Thad O'Day (Day-Daley Petroleum Assoc.); J. H. Gibson Surv. 1; 11 mi. N, 1 W Brady	2643	1370	2150?	*	1273+	780?
McCulloch County: Sellman 1, Texas Eastern Oil Co.; C. Beag Surv. 904; 3½ mi. ENE Rochelle	2005	578	1350	*	1354+	772
McCulloch County: J. S. Wall farm (water well); Werstorfer Surv. 330; 4 mi. SW Brady	1836	466	1395	*	1270+	929
McCulloch County: White 1, Thomas et al; Fisher and Miller Surv. 2586, A-362; 1 mi. E Whiteland	3406	1140	1840?	2982	1842	700
McCulloch County: Zelle 1, Prairie Oil and Gas Co.; H.&T.C. Ry.Co. Surv. 89; 4 mi. NW Lohn	3516	1810	2485?	3309	1439	675
Mills County; Locklear 1, The Texas Co.; Sam Cates Surv.; 8 mi. W, 1 N Goldthwaite	3324	1913	*	*	1411+	1411+
Palo Pinto County: Texas and Pacific Coal and Oil Co., Fee 1, Lassiter et al; A.B.&M. Surv., Sec. 5; 1 mi. from W, 6 from N county line	5630	4029	*	*	1601+	1601+
Reagan County: University 1-C, Big Lake Oil Co.; Big Lake oil field	9562	8618	*	*	944+	944+
San Saba County: Moore 1, Cayce Petroleum Co.; C. Hernandez Surv.; 8 mi. NE San Saba	1659	1281?	1631	1655	374[82]	350
San Saba County: Moore 1, Wilmott et al; C. Hernandez Surv., Bl. 78; 7 mi. NE San Saba	3087	1066	2870	*	2021+	1804
Taylor County: Webb 1, Jamison et al; L. A. L. Surv., Sec. 46; 12 mi. SSE Abilene; 3 mi. from E, 13 from S county line	6016	4770	5304	5809	1039	534

[82]This well is believed to have crossed a fault in drilling, thus accounting for the reduced thickness of the early Paleozoic.

No continuous section showing the full thickness of the Ellenburger in its outcropping belt in the Llano uplift has been measured. However, from their work in this region, Dake and Bridge find the whole thickness to be about 2000 feet.[83] This measurement applies to the central or eastern belt of outcrop. Westward the formation thins by absence of some of the older members.

As shown by these records, the Upper Cambrian and Lower Ordovician sediments, considered as a whole, form a wedge, thickest at the eastern margin of their known belt of occurrence and thinning to the northwest. A thickness map based on these records of the thickness of the Ellenburger limestone is given in Figure 7. In the Llano region the later formations of the Ellenburger group are

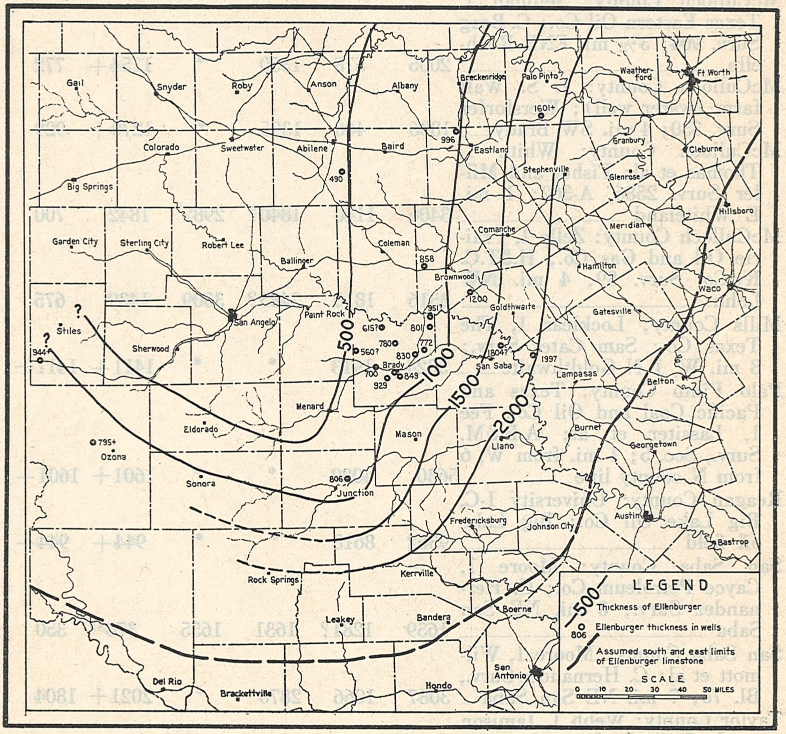

Fig. 7. Map showing the present thickness of the Ellenburger limestone in Central Texas.

[83]Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas: Bull. Geol. Soc. Amer., vol. 43, p. 739, 1932.

found to reach farthest west overlapping and extending westward beyond the limits of some of the earlier formations of this group. A similar overlap possibly accounts for thinning of limestone as a whole to the northwest.

These records show that the thickness of the early Paleozoic is unaffected by the Llano region. This observation is of special importance in structural studies since it indicates that the Llano uplift did not then exist. Post-Bend erosion removed much of the early Paleozoic from the Red River uplift, and the records on that uplift are much less satisfactory. However, the fact that as much as 1040 feet of early Paleozoic is present (Muenster Oil Company No. 1 Yosten) suggests, together with other considerations, that the Red River uplift likewise was not in existence in early Paleozoic time.

In the Llano region and thence northwards to Red River, the Lower Ordovician is followed by a long unrecorded interval including all of Middle and Upper Ordovician, Silurian, Devonian, and a part of Mississippian time. What the condition of this region was during this long interval can be only imperfectly determined. Had the region been subjected to active erosion for so long a period the Paleozoic sediments as a whole surely would have been entirely removed in some places. On the other hand, if any considerable thickness of sediments had accumulated in this region during these periods it seems probable that some remnants would have persisted in structurally low areas. Neither of these conditions prevails. It is true that Richmond sediments have been reported in Young County and that Chattanooga shale has been suspected in Edwards County. Neither of these records, however, is sufficiently well proven to justify acceptance. A possible hypothesis is that this part of the state remained so nearly at sea level during this long interval of time as neither to receive thick deposits of sediments nor to suffer severe erosion. This hypothesis does not preclude the possibility of thin deposits of any one of the intervening periods, such as the occurrence of Simpson sediments in Crockett and Reagan counties, and the reported, but not verified, occurrence of Richmond sediments in Young County. Under this hypothesis obviously some erosion of the top of the Ellenburger occurred but not sufficient to remove entirely the limestone previous to Bend deposition. One may, therefore, entertain the hypothesis of a low lying land area in Central Texas only partly emergent during a large part of mid-Paleozoic time.

The next positive observation with respect to structural correlation is derived from the distribution of Mississippian formations. The Chappel formation, regarded as of Boone or Osage age, is present as a deposit of a few feet thickness, locally exposed. In one locality this formation rests on Ellenburger of Roubidoux age and in another locality on Ellenburger of Cotter age, thus indicating exposure and erosion in Central Texas in pre-Boone time. The original thickness of this formation is undetermined since the amount removed by erosion previous to deposition of the next overlying formation is unknown. This mid-Mississippian formation was either of reduced thickness over the uplift or was subjected to erosion on account of the uplift, either of which interpretations would mean that the Llano uplift originated as a positive element as early as mid-Mississippian time.

A similar indication is given by the Barnett formation of Upper Mississippian age. On the flanks of the uplift, as in San Saba County, the Barnett formation has a thickness of from 35 to 50 feet, while underground to the north its thickness increases to 150 or more feet. The implication is much the same as for the Chappel formation. Either the formation thinned approaching an existing positive element, or erosion removed a part of the formation previous to the deposition of the overlying Marble Falls formation. It seems probable that the Barnett thinned approaching the Llano region but extended across this region.

The late Pennsylvanian seas may have spread entirely across the Llano region. Positive determination of the full extent of the seas across this region. however, remains in doubt owing to the fact that post-Pennsylvanian-pre-Cretaceous erosion removed whatever late Pennsylvanian sediments were deposited on the central and southeastern parts of the uplift. That the Cretaceous inundation spread entirely across the region is more definitely established. During the long interval between the close of Paleozoic deposition in this region and the return of the seas in Cretaceous time, erosion had removed all the Paleozoic sediments from parts of this uplift and exposed the pre-Cambrian schists and granites. Hence the Cretaceous rests on the truncated margins of all formations from pre-Cambrian to late Pennsylvanian. The Cretaceous, in turn, has been largely removed from the central part of the uplift. However, the position of the Cretaceous in the bordering rim of the present basin indicates that these deposits formerly extended across the entire region.

There has been remarkably little deformation in this region in post-Cretaceous time. The Cretaceous formations are but slightly deformed, and the regional dip is apparently unaffected by the uplift. Since Cretaceous time this region has remained dry land.

LLANO FAULT SYSTEM

Extensive faulting occurred in Central Texas in post-Bend time. While there is much variation, the trend of these faults is on the average northeast-southwest. The faults are found in all parts of the uplift but are probably most numerous and largest at the north side of the uplift adjacent to the Bend arch and at the northeast side adjacent to the Lampasas arch. The faulting undoubtedly extends far to the northeast and southwest of the uplift under the covering of late Pennsylvanian and Cretaceous sediments. This faulting is here designated as the Llano system of faults.

It is not within the limits of this volume to describe the individual faults of this system. Many of those of the Llano and Burnet quadrangles are shown in the folio map of that region.[84] The largest faults of the region are indicated in Plate I (in pocket). All are normal or gravity faults, often forming extensive grabens. The several structural arches originating in the Llano uplift will be described later (p. 87).

EDWARDS PLATEAU REGION[85]

The Edwards Plateau includes an extensive region in Central Texas lying chiefly west, south, and east of the Llano uplift. At the south and east this plateau extends to the Gulf Coastal Plain. Its northward extent is in the main limited by the northern margin of Cretaceous deposits in this part of the state except east of the

[84]Paige, Sidney, Description of the Llano and Burnet quadrangles: U. S. Geol. Surv., Geol Atlas, Llano-Burnet folio (No. 183), 16 pp., 1912.

[85]Among publications relating to structural features in or underlying the Edwards Plateau region cited in the bibliography and subject index of Vol. I are the following: Baker, 15; Cartwright, 201a; Cheney, 246; Dawson, Hanna, and Kirby, 398; Hill, 800 and 803; Hill and Vaughan, 794 and 795; Liddle and Prettyman, 991; Sellards, 1402.

Llano uplift where near Colorado River it merges with the Grand Prairie region. To the west, this region is often considered as extending to the mountains of west Texas. However, only that part east of Pecos River will be discussed in this section of the report. The Edwards Plateau was named and defined by R. T. Hill. The surface formations of the Edwards Plateau, which are Cretaceous in age, are in the main relatively level-lying but with moderate eastward or southward dip.

POST-CRETACEOUS DEFORMATION IN THE EDWARDS PLATEAU

No great post-Cretaceous structural deformation has occurred in this region. The uplift which brought the region to its present elevation of from 1000 to 3000 feet above sea level was of the nature of a continental uplift. Such structural features as were developed in the plateau proper include relatively slight domes, anticlines, or synclines. At its south and east margins, the plateau borders on the Coastal Plain, and the structural features in the Cretaceous formations there partake in some degree of the disturbances of the Balcones zone which have already been described. Near this border, also, are found some intruded igneous rocks.

In the central part of the plateau, the Paleozoic floor under the Cretaceous lies almost level with no more than a slight southeastward slope. However, approaching the Balcones zone the slope increases and at the margin of the zone becomes abrupt, probably including faulting in this zone.

PRE-CRETACEOUS STRUCTURAL FEATURES IN THE EDWARDS PLATEAU

Underneath the Cretaceous of the Edwards Plateau region are varied rock formations and imperfectly known structural conditions. The pre-Cretaceous rocks of the Balcones zone, including a small part of the south and east margins of the plateau, have already been described (p. 49). These rocks are of Paleozoic age and probably are of complicated structure. Under the central part of the plateau, likewise, are Paleozoic formations. Although structural features in these rocks of the central part of the plateau are imperfectly known, it is, nevertheless, evident that these Paleozoic formations have been strongly folded and faulted. Individual faults can seldom be recognized, and only the major folds or arches can be outlined through the aid of well records.

Several arches originating from the Llano uplift extend under the Cretaceous and Upper Pennsylvanian formations. Of these, two, the Concho arch extending northwest, and the San Marcos arch plunging southeast, coincide in position and trend with the known pre-Cambrian folds. Three others, the Lampasas arch trending northeast, the Edwards arch trending southwest, and the Bend arch trending north-northeast, are approximately at right angles to the lines of pre-Cambrian folding and trend approximately with the extensive faulting of post-Bend time. The location of these arches is indicated on Figure 1, page 12. Between the arches are basins, one of which has been named the Kerr basin (Vol. I, p. 136).

SAN MARCOS ARCH

At the southeastern side of the Llano uplift it is possible to detect, partly from exposures and partly from well records, a broad arch trending southeast. This arch is probably the origin, or roots, as it were, of the San Marcos arch. The northeast slope of the arch is seen in the northeast dipping strata of Cambrian, Ordovician, and Pennsylvanian age exposed in Pedernales River in Blanco County. The approximate axis of the arch is indicated by exposures of granite in and near Pedernales River 10 or 12 miles west of Johnson City. Wells drilled on this arch southeast of Johnson City have shown Cretaceous resting on Ellenburger, the Mississippian and Pennsylvanian being absent on the arch. In addition to the surface exposures, the position of the arch is indicated by wells in eastern Kendall and western Blanco counties. The arch mapped on the Ellenburger limestone is shown on Plate I. The southeastward extension of this arch into the Coastal Plain, where it is overlain by a Cretaceous section of reduced thickness, has already been described (p. 44).

EDWARDS ARCH

A broad "nose" or arch trends southwestward from the Llano uplift. As mapped on the Ellenburger limestone, it is recognizable in Kimble and Edwards counties. Its trend, as may be seen from Plate I, is approximately at right angles to the trend of the San Marcos arch. Faulting at the southeast boundary of this structural feature is probably indicated by the few wells that have been drilled. Such apparent faulting, not cutting the surface formations, may reasonably be inferred to be of the same system as that already described for the Llano uplift. This uplift is recognized chiefly from wells in the northeastern part of Edwards County where the Ellenburger limestone is reached at depth of 3800 to 4400 (—1500 to —2000 ±) feet.

KERR BASIN

Occupying the syncline between the San Marcos and Edwards arches is the Kerr basin situated in Real, southwestern Kerr, and western Bandera counties. This basin of deposition, now concealed by the overlying Cretaceous formations, has received a considerable thickness of Pennsylvanian sediments. A well on the Love ranch in southwestern Kerr County reached Ellenburger at or near depth 5605 (—3225 ±) feet.

CONCHO ARCH

The existence of the Concho arch, originally called Concho divide, was first recognized by M. G. Cheney.[86] This arch, which extends northwest from the Llano uplift, is essentially in the trend of pre-Cambrian folding and of the San Marcos arch already described. The Concho arch was re-elevated in post-Bend time. That part of the fold southeast of the Llano uplift may likewise have been re-elevated at this time, although the late Pennsylvanian formations being absent, such uplift cannot be determined. The post-Bend uplift of the Llano region has already been discussed.

The Concho arch was severely eroded in post-Bend time, and the formation on the arch rests, as shown by well records, on formations as old as Cambrian.[87] In a structural map drawn on the top of the Ellenburger limestone as in Plate I, this arch is not conspicuous owing to the fact that it has been severely planed off and the Ellenburger top lowered by erosion.

The Lower Pennsylvanian formations (Bend group) underlying the Edwards Plateau west of the Llano uplift thin to the west and

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[86]Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 557–594, 1929.

[87]Among wells on this arch interpreted as having Canyon resting on Cambrian are Sabens No. 1 Davis in the northeastern part of Menard County and the Haby and Allison well in the southwestern part of McCulloch County.

were found to be absent in the Big Lake oil field of Reagan County and in the one well drilled to the Ordovician in Crockett County. The post-Bend Pennsylvanian formations underlying this plateau which west of the Llano uplift contain heavy, light-colored limestones change westward to black shales and black limestones. They thin westward possibly by erosion, as shown by the reduced thickness found in the Big Lake oil field and in the deep well in Crockett County. The Permian formations, which underlie a part of the plateau and which in eastern Sutton County contain limestones, grade westward into black shales and black limestones. These changes occur in passing into the Permian basin, subsequently described.

LAMPASAS ARCH

The Lampasas arch was recognized and described by the writer[88] in 1920. It is a broad arch originating in the northeastern part of the Llano uplift and trending northeast through the western part of Lampasas County. This arch is recognized from relatively few well records, and it is not possible to determine to what extent the arch is limited at either side by faulting. In 1916 E. T. Dumble described and named the Lampasas geanticlinal (Rice Institute Pamphlet, vol. 3, p. 155), which apparently is the same structural feature as that here referred to as the Lampasas arch. The term arch seems more appropriate to this feature than geanticlinal.

The Bend arch or flexure is a very pronounced structural feature which trends from the Llano uplift slightly east of north through north-central Texas. This arch will be described later in this paper.

GRAND PRAIRIE REGION[89]

Grand Prairie is a name proposed by Hill[90] including in Texas a belt of country lying west of the Balcones zone and north of the Llano uplift. It is the modified northeastward continuation of the

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[88]Sellards, E. H., On the underground position of the Ellenburger formation in north central Texas: Univ. Texas Bull. 1849, p. 11, 1920.

[89]Among publications relating to structural conditions in or under the Grand Prairie region cited in the bibliography and subject index of Vol. I are the following: Adkins, 14; Adkins and Arick, 16; Bay, 82; Bullard, 177; Bullard and Cuyler, 176; Bybee and Bullard, 189; Cheney, 246 and 247; Hager, 641a; Hawtof, 675; Hill, 803; Scott, 1394; Scott and Armstrong, 1398b and 1398c; Sellards, 1403 and 1441; Taff, 1574; Tomlinson. 1606b; Udden, 1673; Winton, 1791; Winton and Adkins, 1789; Winton and Scott, 1790.

[90]Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S., Geol. Surv., 21st Ann. Rept., pt. 7, p. 71, 1901.

Edwards Plateau, and, as on that plateau, its surface formations are those of the Comanche Cretaceous series. These Cretaceous formations dip gently to the east or southeast. Some faulting is present particularly near the Balcones zone, but in the main these formations present no large structural features other than the mild regional eastward dip. Under the Cretaceous covering, the Grand Prairie region has a floor of Paleozoic formations. To the southern part of this region adjacent to the Llano uplift, R. T. Hill applied the term Lampasas Cut Plain.

In the southern part of its area, the Grand Prairie region at its eastern margin overlies the Llanoria geosyncline, the rocks and structural features of which have already been described. The Lampasas arch in the Paleozoic rock which underlies the southern part of Grand Prairie has likewise been previously mentioned.

Adjacent to the Llanoria geosyncline, under the Cretaceous, is a great thickness of Strawn sediments. The basin containing these sediments, which developed during Strawn time, has been named the Strawn basin.[91] The basin is well developed in and near Bosque County. A well on the Myrick farm in the northeastern part of that county, which was drilled to depth 6111 feet, did not pass through the Pennsylvanian sediments.

In the vicinity of Fort Worth is a great syncline, here named the Fort Worth syncline, which extends northwestward to southern Clay County. The full thickness of the Pennsylvanian in this syncline is not known, although the Strawn sediments in Wise County, according to Scott and Armstrong,[92] reach a thickness of 4300 feet.

The Muenster arch of the Red River uplift underlies the Cretaceous near Red River, and north of this uplift at and near the state line is a corresponding syncline. The Red River uplift and associated structural features will be described later.

These several structural features in the Paleozoic and pre-Paleozoic strata are scarcely, if at all, reflected in the overlying blanket of Cretaceous formations of the Grand Prairie and Edwards Plateau regions, which formations, as previously stated, dip gently eastward.

[91]Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, p. 570, 1929.

[92]Scott, Gayle, and Armstrong, J. M., The geology of Wise County, Texas: Univ. Texas Bull. 3224, 77 pp., 1932.

OSAGE PLAINS REGION[93]

The Osage Plains region of north-central Texas extends from the Edwards Plateau and the Llano uplift north to Red River. Westward it reaches to the foot of the High Plains and eastward to the Cretaceous of the Grand Prairie region.[94] Aside from some Cretaceous and Triassic remnants the surface formations are of Pennsylvanian and Permian age. The regional dip of these formations in this area is northwest, the average dip approximating 50 feet per mile. These surface formations thus form a west sloping homocline.[95] These strata include local unconformities and probably important disconformities, as well as some small scale faulting. There are also structural features sufficient to afford storage for oil and gas. However, the formations overlying the Bend in this region have not been affected by any great structural deformation. In contrast to the slight deformation in the surface strata is the much more pronounced folding which involves the Bend and all older formations. The large buried structural features of this region are the Bend arch and the Red River uplift.

BEND ARCH

The Bend structural feature was recognized as a northward plunging anticline by M. G. Cheney[96] in 1918. As contoured on the top of the Ellenburger limestone (Pl. I) it is the most pronounced of the arches originating from the Llano uplift. This arch approximately parallels in trend the post-Bend fault system of the Llano uplift and may have an actual relationship to that faulting. Such relationship would account for the asymmetric form of the arch and

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[93]Among publications relating to structural features in the Osage Plains region of north-central Texas cited in the bibliography of Vol. I are the following: Adams, 6; Bay, 82; Beede, 88 and 90; Beede and Bentley, 92; Beede and Christner, 96 and 97; Beede and Waite, 87; Cheney, 244a, 245, 246, 247, and 247a; Cheney and Harris, 247c; Bureau of Economic Geology, county maps, 1853; Case, 208c; Cummins, 342; Dobbin, 432; Dodson, 432b; Esgen, 527; Goldman, 598; Henderson, 704; Patton, 1185; Plummer, 1227; Plummer and Moore, 1228; Pratt, 1258; Reeves, 1296; Ross, 1352; Sellards, 1403 and 1405; Shaw, 1449; Smiley, 1492; Storm, 1554; Udden, 1673; Wade, 1699.

[94]The name Osage section of the central lowland of the interior plains of the United States was proposed by Fennemann (U. S. Geol. Surv., Bull. 730, p. 116, 1923) for plains in Oklahoma and Texas. For the Texas plain, the term Wichita plain would be appropriate since this region in Texas was the home of the Wichita Indians

[95]Formation names and stratigraphic sequence in these sediments are given in Vol. I, pp. 98–115.

[96]Cheney, M. G., Economic importance of the Bend series in north-central Texas as a source of petroleum supply: Oil Trade Journal, vol. 9, pp. 109–110, 1918.

for its relatively steep, probably faulted, east slope. It is to be noted that this arch originates not centrally as do the other arches but from the west side of the uplift. It is possible that the Bend arch extends south to and joins with the Edwards arch previously described. This cannot be determined until more information from deep wells is at hand. However, it seems more probable that the Edwards arch at the southwest side is traceable through and joins with the Lampasas arch at the northeast side of the uplift, and that the Bend arch, while it touches the uplift at its northwest side, has no counterpart in or south of the uplift.

An explanation of the origin of the Bend arch has been given by Levorsen,[97] who believes that in Palo Pinto time there was a southeast dipping homocline extending continuously or nearly so from northern Arkansas to Central Texas. Later, subsequent to Pennsylvanian and Permian deposition, he states, the entire region was tilted northwestward, resulting in the regional northwest dip in the Permian and late Pennsylvanian sediments. The final result of these two movements which occurred at widely different times was to produce the Bend arch of Central Texas and a similar arch in the Ozark region of Oklahoma and Missouri.

In several publications, M. G. Cheney has presented and defended the theory that the Bend arch, so-called, which he prefers to call the Bend divide, has resulted from two separate earth movements. The first of these was the formation of the Strawn basin, the effect of which was to flex strongly the east side of a post-Bend table-land, forming a steep east sloping homocline with some faulting. The next earth movement, according to Cheney, came much later in the form of gradual tilting of the entire region during Upper Pennsylvanian and Permian time incident to the formation of the great Pennsylvanian-Permian basin of west Texas. The effect of this tilting was to form the present west sloping homocline in the post-Bend Paleozoic strata. Cheney[98] recognizes in the Bend flexure two parts, the Comanche-Young flexure at the east side and the San Saba-Callahan flexure at the west side.

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[97]Levorsen, A. I., Convergence studies in the Mid-Continent region: Bull. Amer. Assoc. Petr. Geol., vol. 11, p. 679, 1927.

[98]Cheney, M. G., Stratigraphic and structural studies in north-central Texas: Univ. Texas Bull. 2913, p. 11, 1929; and History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, p. 573, 1929.

This hypothesis has merits in that it accounts for many of the observations already made. It does not, however, explain why the arch becomes structurally more prominently developed approaching the Llano uplift where there is no Strawn basin. The arch plunges northward. The Strawn basin may plunge northward also, but this is undetermined. To the writer, it seems probable that the Bend arch as a structural feature has been modified by the northeast-southwest post-Bend fault system which is seen best exposed in the Llano uplift. This fault system terminates northward, as does the Bend arch, before reaching the Red River uplift. This system of faulting, as well as the east limit of the flexure, may have resulted from the formation of the Strawn basin. The northward plunge of the arch is shown in Plate I.

The Bend arch underlies one of the extensive and prolific oil and gas producing regions of the state. Production is obtained from local structural features on the arch. In the surface strata over the arch the structural features appear as northwest plunging anticlines, that is, with the dip, and as terraces trending with the strike or as combinations of these. Less commonly, anticlines in the surface rocks trend in directions other than northwest. Doming in the Pennsylvanian rocks at the surface occurs rarely. In the early Pennsylvanian formations, the Bend group, which is separated from the later Pennsylvanian by an angular unconformity, structural conditions are much more complicated. Anticlines in the surface rocks are usually more pronounced in these older formations and domes are not infrequent. According to Reeves,[99] a northeast-southwest trend is evident in the rocks of the Bend series in the Ranger district.

RED RIVER UPLIFT[100]

The Red River uplift as a whole is a buried structural feature which extends adjacent to Red River from Denton County to Cottle County or beyond and hence underlies a part of both the Grand

[99]Reeves, Frank, Geology of the Ranger oil field, Texas: U. S. Geol. Surv., Bull. 736, pp. 111–170, 1922.

[100]*Among publications relating to structural features in the Red River uplift cited in the* bibliography of Vol. I are the following: Barnes, 58a; Barton, 69b; Becker, Murray and Fulton, 83a; Beede and Christner, 96; Bullard and Cuyler, 176; Bybee and Bullard, 189; Case, 208c and 221b; Cheney, 246 and 247; Fuqua and Thompson, 550; Glenn, 594; Gordon, 611; Hager, 641a; Hawtof, 675 and 676; Hughes, 858b; Kendrick and McLaughlin, 902; Munn 1145a; Rogers, 1346; Sellards, Tharp, and Hill, 1410; Shaw, 1449; Shaw and Ports, 1450; Smiley, 1492; Tomlinson, 1606b; Udden, 1673; Udden and Phillips, 1632; Winton, 1791; Wrather, 1803.

Prairie and the Osage Plains regions. While this buried range has thus an east-west extent of some 200 miles its width is slight, being no more than a few miles. If the overlying blanketing Cretaceous and late Paleozoic deposits were removed, this structural feature would not appear as a continuous ridge through all this distance but would be found to be a series of scattered peaks on a more or less continuous upland. Aside from isolated peaks, one range would be found to be separated from another by a "saddle," and spurs of the mountain would be found to cross Red River and extend northward towards the Wichita Mountains; faulting would probably be found to be present, the trend of the major faults being not with the axis of the uplift as a whole, which is nearly east-west, but diagonal to it in a northwest-southeast direction. Erosion on structural highs was so extensive as to remove all the older Paleozoic, allowing the Upper Pennsylvanian, at some localities, to rest directly on the pre-Cambrian.[101] These northwest-southeast trending folds and faults form an *en échelon* arrangement of highs in the Red River region. Within the Red River uplift as a whole, two principal structural divisions have been recognized, the Muenster arch and the Electra arch.[102]

MUENSTER ARCH

The Muenster arch makes up the eastern part of the Red River uplift in Denton, Cooke, and Montague counties, Texas, and extends into Jefferson County, Oklahoma. Its trend is northwest-southeast and is thus not with the trend of the uplift as a whole but diagonal to that trend. How far this arch continues into Oklahoma is not known. It trends towards the Wichita Mountains and can be followed in this direction across Red River. Bunn[103] has described an uplift in Jefferson County, Oklahoma, named by him the Waurika arch. This arch, according to Bunn, is structurally lower and lies *en échelon* with the Nocona uplift, which is a part of the Muenster arch. More recently, Van Weelden has concluded, on the basis of

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[101]For list of wells on this uplift in which the early Pennsylvanian is wanting, see Vol. I, pp. 198 (Clay Co.), 203 (Cooke Co.), 206 (Denton Co.), 211 (Foard Co.), 219 (Montague Co.), 227 (Wichita Co.), 228 (Wilbarger Co.), and 229 (Cottle Co.).

[102]Cheney, M. G., History of the Carboniferous sediments of the Mid-Continent oil field: Bull. Amer. Assoc. Petr. Geol., vol. 13, p. 585, 1929.

[103]Bunn, John R., Jefferson County, *in* Oil and Gas in Oklahoma: Oklahoma Geol. Surv., Bull. 40, Vol. II, p. 353, 1930.

geophysical observations, that the Muenster arch is connected with the Wichita Mountains. From gravimetric and magnetic data he maps under the name of Walters arch a structural feature lying chiefly in Cotton County, Oklahoma, which is intermediate between the Wichita Mountains and the Muenster arch. From these data Van Weelden[104] concludes that the Muenster arch is connected directly with the Wichita Mountains and that the Ringling deep, postulated by Van der Gracht and others, either is non-existent or is much restricted and does not intervene between the Muenster arch and the Wichita Mountains.

ELECTRA ARCH

The Electra arch makes up the western part of the Red River uplift in Clay, Wichita, Wilbarger, Foard, and Cottle counties. This arch, which trends east-west, is separated from the Muenster arch by a deep trough or "saddle." Faulting with northwest-southeast trend is probably present cutting this arch and giving *en échelon* arrangement to its component parts.

SUMMARY OF STRUCTURAL HISTORY OF CENTRAL TEXAS

1. At the close of pre-Cambrian time, or more exactly at the beginning of Upper Cambrian time, Central Texas presented complicated structural conditions which, however, are but imperfectly determined. In the Llano region, where pre-Cambrian strata are exposed, a northwest-southeast structural trend antedating Upper Cambrian is evident. The anticlinal folds of that trend plunge southeast. Other highly complicated structural conditions of these strata are associated with the intruded igneous rocks. The region as a whole had been eroded and the folds beveled previous to the incursions of the Upper Cambrian and succeeding seas. The extensive series of Paleozoic formations was deposited upon this beveled and structurally complicated pre-Upper Cambrian surface.

2. The Cambro-Ordovician seas extended across Central Texas as shown in maps issued by the Bureau of Economic Geology in 1931, reproduced in Figures 7 and 8 of Volume I of The Geology of Texas, University of Texas Bulletin 3232, pages 68 and 81.

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[104]Van Weelden, A., Regional tectonical features of the Wichita-Arbuckle mountain region in the light of geophysical observations: Oil Weekly, vol. 70, pp. 27–30, Sept. 11, 1933.

3. The Llano uplift was non-existent and the region was not a positive element in the Cambro-Ordovician sea. This conclusion is supported by a thickness map of the Ellenburger (Cambro-Ordovician) limestone. This limestone thins to the west or northwest. Such thinning is proven by well records as well as in the surface exposures. This westward thinning cannot be assigned to the influence of a Llano element since it occurs off as well as on the present Llano uplift.

4. An extensive region in Central Texas is believed to have remained neither deeply submerged nor greatly elevated during Middle and Upper Ordovician, Silurian, Devonian, and a part of Lower Mississippian time. The region here referred to extends from the Red River to and including the Llano uplift. If deep submergence had occurred, it seems highly probable that some part of the sediments accumulated would have remained and would have been detected either in surface exposures or in well drilling. Similarly, if the region had been greatly elevated, erosion would have proceeded irregularly, and in places the Ellenburger would have been entirely removed. The uniform spread of the Ellenburger except where removed by erosion in Pennsylvanian or later time indicates no pronounced elevation of this region in pre-Mississippian time.

5. The Llano uplift appeared as a positive element. but probably not as a pronounced uplift, in Mississippian time. The reason for postulating the appearance of the Llano uplift as a positive element in Mississippian time is the thinning of the late Mississippian formation (Barnett shale) approaching this region. The mid-Mississippian formation of Boone age (Chappel limestone) probably also thins approaching the Llano uplift, although there is much less available evidence as to thickness of this formation.

6. A post-Mississippian-pre-Pennsylvanian uplift occurred in the Llano region sufficient to cause a break in sedimentation on the uplift between the Barnett (Mississippian) and the Bend (Pennsylvanian) formations. This break representing either overlap or erosion is shown by the fact that the Marble Falls limestone in places rests directly upon the Ellenburger limestone.

7. The Barnett formation probably extended entirely across the present Llano uplift. While the Barnett thins approaching the uplift, there seems to be no gradation towards a shore facies, from

which it is inferred that the source of sediments is not from the present uplift and that the formation spread across the Llano region and was subsequently removed by erosion at some localities previous to the deposition of the overlying Lower Pennsylvanian sediments (Bend group).

8. The principal uplift in the Llano region was post-Bend and pre-Canyon in age. This assignment of age of the principal uplift in the Llano region is well substantiated. No erosion, so far as known, of such severity as to remove the Ellenburger entirely occurred in the Llano uplift until after the close of Bend time. This conclusion is believed to be supported by the observation that where the Bend is present the Ellenburger is found to retain approximately its full thickness as of that locality. Conversely, localities are known at which erosion in post-Bend-pre-Canyon time was so severe as to partly or entirely remove the Ellenburger, allowing Upper Pennsylvanian to rest on either the thinned Ellenburger or, in some localities, on Cambrian below the Ellenburger. Aside from residual conglomerates, "detrital zones," coarse clastic sediments first came into the section in this part of the state in post-Bend time. A strong angular unconformity marks the Bend-post-Bend break.

9. Extensive faulting occurred in the Llano uplift in post-Bend time, the fault trend being northeast. Whether this faulting occurred as a result of the post-Bend uplift or occurred somewhat later than this uplift is undetermined. Likewise, whether the faulting is immediately post-Bend in time or is progressive through a part of Strawn time is undetermined. More information is needed on the time of this faulting.

10. The diastrophic movements in the hinterland (Llanoria) did not very strongly affect the foreland (Central Texas) until after the close of Bend time.

11. The basins associated with these uplifts, the Strawn and Kerr basins in Texas, were initiated at the same time as the uplifts and represent differential warping in the foreland. These basins continued to receive sediments through Strawn time and were progressively deepened.

12. The warping may have resulted in part from the closing in on the foreland of westward moving salients of the Llanoria region.

Thus in the Fort Worth region the movement was westward, in the San Antonio region northwestward, and in the Val Verde region northward.

13. The mild uplifts of pre-Bend time in the foreland may reasonably be regarded as the effect of earlier and possibly more pronounced movements in the hinterland.

14. The Llano uplift previous to post-Bend time was not a source of large amounts of sediments, and the Llanoria land mass continued to be the principal source of sediments through Pennsylvanian time.

15. Strawn deposition began in the recently formed Strawn and Kerr basins and later extended westward as much thinner deposits.

16. The Llano region in early Strawn time was not greatly uplifted and apparently did not supply materials to the Strawn conglomerate. On the contrary, the Strawn strata strike as if to pass directly across the Llano uplift and to some extent overlap the uplift without having received much sediments from it.

17. The Strawn shore line seems not to have been greatly to the east of the east margin of the present Llano uplift.

18. The northeast trending faults of the Llano region, Llano fault system, may have formed progressively as the basins were depressed during Strawn time.

19. The shore line fluctuated during Upper Pennsylvanian time, but in the main the Llanoria land mass crowded the shore line westward.

20. The present Red River uplift is believed likewise to have been initiated either in or at the close of Mississippian time. The record of events in the Red River region is much less well known than in the Llano region. The Ellenburger limestone evidently spread entirely across this region, although it was in places removed by erosion, interpreted as of mid-Pennsylvanian time. Either the Mississippian seas did not cross this region or the resulting sediments were removed by erosion previous to Lower Pennsylvanian time. This conclusion is based on the apparent absence of Barnett on the Red River uplift and the apparent presence of Bend immediately overlying the Ellenburger at some localities. At the present time it can only be said that the history of the Red River region in Mississippian time appears to coincide with that of the Llano region.

21. The Llano uplift and the Red River uplift, with the possible exception of its westernmost part, were submerged by the Lower Pennsylvanian (Bend) sea. Submergence of these two regions is indicated by the present distribution of the Bend series. On the Red River uplift, however, only limited remnants of the Bend remain.

22. The Paleozoic history of Central Texas is dominated by a westward crowding land mass which formed and later obliterated the Llanoria geosyncline, then formed and obliterated the Strawn basin, and terminated its activities only with the formation of the great Permian basin which was filled by sediments and obliterated by continental uplift in Mesozoic time.

HIGH PLAINS REGION[105]

The High Plains of Texas include the Panhandle region of the northwest part of the state (fig. 3, p. 32). This entire region is blanketed by Cenozoic deposits which show no great structural deformation. Locally there are exposures of Cretaceous and Triassic deposits which, likewise, are but slightly deformed. The deeply entrenched Canadian River, which flows across the region, and several smaller streams, which rise in the High Plains and trench its east margin, expose Permian sediments. These late Paleozoic formations have been deformed to the extent of producing, at some localities, structural features important in the accumulation of oil and gas.

The most pronounced structural features of the northern High Plains developed in the Permian and older strata are the Amarillo uplift and the Anadarko syncline, both of which are largely concealed at the surface by later deposits.

AMARILLO UPLIFT

Entirely buried under the surface formations are the Amarillo Mountains which are approximately in line with and probably represent the westward extension of the Wichita Mountains of Oklahoma. Like the Wichitas, this range of buried mountains consists of a series of peaks with intervening valleys or "saddles." The trend of the uplift as a whole is west-northwest to east-southeast or

[105]Among publications relating to structural features in the Texas High Plains region including the Amarillo uplift and the Anadarko basin cited in the bibliography of Volume I are the following: Baker, 42 and 1288a; Bauer, 78 and 79; Bullard, 175; Cotner and Crum, 321b; Gould, 614b, 615, and 616; Gould and Lewis, 623; Gould and Willis, 625; Harrison, 670; Patton, 1180; Powers, 1251a; Pratt, 1264; Reed and Longnecker, 1288a; Van der Gracht, 1677.

almost east-west. The mountains are cut by faults or *en échelon* folds which trend more nearly northwest-southeast, although some trend nearly east-west. Some of the faults of this region, according to Cotner and Crum,[106] have a greater displacement in the older than in the younger Permian formations, thus indicating that they formed progressively during Permian time.

The westernmost known peak associated with this system in Texas is the Bravo dome chiefly in Oldham County, which is adjacent to and may be a part of the pre-Cambrian plateau of New Mexico. A deep trough separates this dome from the Amarillo uplift proper. This dome has not produced oil or gas. Other domes or peaks in the Paleozoic formations are: John Ray dome, chiefly in Potter County; Bush dome in Potter County; 6666 dome in Carson County; Le Fors dome in Gray County; and Lela dome, chiefly in Wheeler County. A depression northwest of the Amarillo uplift is known as Dalhart basin. It lies chiefly in Hartley County and is intermediate in position between the Amarillo uplift and the New Mexico region. This basin is confluent with the basin south of the uplift through the narrow trough east of the Bravo dome.

Following is a summary of structural conditions in this uplift.

1. The structural conditions of pre-Cambrian time in the Amarillo region are entirely unknown. Drilling has extended into rocks which are accepted as probably of pre-Cambrian age, but nothing is revealed in these samples as to the structural conditions previous to Cambrian time other than that igneous rocks of various kinds are present and that the pre-Cambrian sediments are altered.

2. Early Paleozoic seas may or may not have extended across this region. The early Paleozoic seas are known to have extended westward to the region of the Wichita Mountains and thence northwestward across western Oklahoma. But that these seas extended across the region of the present Amarillo Mountains is not proven, although drilling may yet prove the presence of Cambrian and Ordovician sediments, south as well as north of the Amarillo Mountains, carrying the implication that such formations formerly extended directly across the now uplifted region.

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[106]Cotner, Victor, and Crum, H. E. Geology and occurrence of natural gas in Amarillo district, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 17, p. 886, 1933

3. The structural history of this region from Middle Ordovician through Lower Pennsylvanian is at present equally as obscure as during the Cambrian and Lower Ordovician. It has already been suggested that a large part of Central Texas probably remained neither deeply submerged nor greatly elevated during Middle and Upper Ordovician, Silurian, Devonian, and Mississippian time. If that hypothesis is true for Central Texas, it is believed to be true also for the Texas High Plains. Mississippian sediments may exist in Texas north of the Amarillo uplift. Whether these and older Paleozoic seas extended across the present Amarillo uplift is undetermined.

4. That the Amarillo Mountains were in existence in Upper Pennsylvanian time is shown by the fact that Upper Pennsylvanian formations contain a feather edge of granite wash derived from the mountains. The subsequent history is that of overlap of Pennsylvanian and Permian formations until the mountains were entirely buried in Permian time.

5. The Amarillo Mountains are cut by faults, the trend of which is prevailingly northwest. These faults are interpreted as having formed possibly coincident with, but in part at least subsequent to, the uplift, their formation having been progressive through much, possibly nearly all, of Permian time.

6. Further information as to the time or times of uplift in the Amarillo region can be obtained apparently at this time only by inference based on the assumed relationship of these mountains to the Wichita Mountains and to the Criner Hills in Oklahoma. In the region of the Wichita Mountains, the Lower Pennsylvanian is apparently unknown, the entire region having been possibly of such elevation as to exclude the Lower Pennsylvanian sea. Becker,[107] however, has recently referred to sediments of possibly older Pennsylvanian and Mississippian age in the Gotebo area in Kiowa County.

Taff,[108] after studying this region, concluded that the uplift of the Wichita Mountains was probably of the same age as that of the

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[107]Becker, Clyde M., Structure and stratigraphy of southwestern Oklahoma: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 41, 1930.

[108]Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma: U. S. Geol. Surv., Prof. Paper 31, p. 80, 1904.

Arbuckle Mountains, which he regarded as having begun near the middle and culminated near the end of Pennsylvanian time. Becker[109] agrees that the principal uplift of the Northeast and Central ridges was of middle to late Pennsylvanian age but considers that there is a possibility that the Southwest ridge may be older. The supposed earlier age of the Southwest ridge is supported, however, only by a thicker accumulation of granite wash on its flanks and by the fact that the faults on the Southwest ridge, according to Becker, strike S. 60° W. to S. 85° W., while those on the Central and Northeast ridges strike approximately S. 60° W. The greater thickness of granite wash and the divergence in the strike of the faults obviously may be due to causes other than a difference in the age of the uplifts. Hoffman,[110] also, is of the opinion that the principal orogeny of the Wichita Mountains began in mid-Pennsylvanian time.

The slight uplift which affected the Llano region in Mississippian time and the uplift which Tomlinson records in the Criner Hills in early Pennsylvanian time may or may not have extended westward to the Wichita and Amarillo mountains. According to Tomlinson,[111] the earliest conglomerates recognized as originating from the Criner Hills are found in the Dornick Hills formation, which possibly is equivalent to the Bend group in Texas. This interpretation places the initial movement recognized in the Criner Hills as coincident, or essentially so, with the post-Mississippian movements referred to in the Llano and Red River uplifts. At the west end of the Criner Hills the uppermost Deese or lower Hoxbar (Strawn or Canyon) rests on the truncated older Paleozoic down to the Cambro-Ordovician. This condition is similar to that found locally at the west side of the Llano unlift where Canyon rests on Cambrian due to post-Bend-pre-Canyon erosion. These conditions are interpreted as indicating an uplift, following Bend time and preceding Canyon time. This uplift is regarded as the principal uplift of the Llano and Red River regions and seems most probably also the time of principal uplift of the Wichita and Amarillo mountains.

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[109]Becker, Clyde M., Structure and stratigiaphy of southwestern Oklahoma: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 41, 1930.

[110]Hoffman, M. G., Geology and petrology of the Wichita Mountains: Oklahoma Geol. Surv., Bull. 52, p. 27, 1930.

[111]Tomlinson, C. W., The Pennsylvanian system in the Ardmore basin: Oklahoma Geol. Surv., Bull. 46, p. 20, 1929.

ANADARKO SYNCLINE

The Anadarko syncline is a broad trough lying immediately north of the Amarillo and Wichita mountains in Texas and Oklahoma. The syncline is asymmetric in form, being steep on the south side, adjacent to the mountains, and of gentle slope on the opposite side, away from the mountains. At the west the trough spoons out in the Texas Panhandle. Eastward, according to Van der Gracht[112] and Van Weelden,[113] it passes south of the Arbuckle Mountains and becomes confluent with the Ardmore basin, and hence continues almost, if not entirely, to the Ouachita Mountains. Van Weelden interprets the syncline as a fore-deep in front of the Wichita range including the Criner Hills and the Amarillo Mountains. The trend of the trough is west-northwest to east-southeast. The formations at the surface in this trough are chiefly those of Permian and late Pennsylvanian age with remnants of Cretaceous and Cenozoic formations.

The basin originated presumably contemporaneously with the uplift of the Amarillo and Wichita mountains and was largely filled with sediments during late Pennsylvanian and Permian time. Mild deformation occurred in post-Permian-pre-Cretaceous time since, according to Bullard, the remnants of the Washita Cretaceous sediments which formerly spread across this region rest with angular unconformity on the beveled edges of the Permian strata adjacent to the mountains.[114] This author finds also that the Cretaceous strata are slightly synclinal in this trough, which he interprets as indicating post-Cretaceous warping of the region.

Because the Cenozoic sediments in the Panhandle region of Texas are thicker in this basin than on the adjacent Amarillo uplift, Baker suggests that the Amarillo uplift was upfolded and the Anadarko basin downfolded contemporaneously with the last Cordilleran orogeny.[115] Compacting of Permian and Pennsylvanian sediments must be recognized as aiding in the formation of this syncline since these sediments are of much greater thickness in the trough than

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[112]Van der Gracht, W. A. J. M. van Waterschoot, The Permo-Carboniferous orogeny in the south-central United States: Koninklijke Akademie van Wetenschappen te Amsterdam, Deel 27, no. 3, 170 pp., 1931. Abst., Bull. Amer. Assoc. Petr. Geol., vol 15, pp. 991–1057, 1931.

[113]Van Weelden, A., Regional tectonical features of the Wichita-Arbuckle mountain region in the light of geophysical observations: Oil Weekly, vol. 70, pp. 27–30, Sept. 11, 1933.

[114]Bullard, F. M., Lower Cretaceous of western Oklahoma; a study of the outlying areas of Lower Cretaceous in Oklahoma and adjacent states: Oklahoma Geol. Surv., Bull. 47, p. 110, 1928.

[115]Baker, C. L., Foreword, Univ. Texas Bull 3231, p. 6, 1933.

on the adjacent uplifts. If such compaction resulted in topographic inequality, this, in turn, would account for a greater thickness of Cenozoic deposits in the trough. However, that the Cordilleran orogeny should have affected the region as postulated by Baker seems probable.

For a large region in the High Plains south of the Amarillo Mountains, structural conditions are very imperfectly known. To the region lying next south of the uplift, Gould and Lewis[116] in 1926 applied the term Palo Duro basin. From lack of deep borings this basin is illy defined, and it cannot be determined at present whether or not there is a localized basin or trough immediately south of the Amarillo uplift.

The Red River uplift trending approximately east-west is known to extend westward to Cottle County; its continuation under the High Plains is possible but is undetermined. Only from deep borings or from geophysical data can the structural and stratigraphic conditions of the central region of the Texas High Plains be determined.

PERMIAN BASIN[117]

The Permian basin is a great structural feature, which, with some partial interruptions, extends from the Pecos Valley region in Texas north-northeastward through Texas and the adjacent parts of eastern New Mexico, through western Oklahoma, central Kansas, and into Nebraska. In this paper further reference will be made only to that part of the basin which lies in Texas and New Mexico.

As to the date of the origin of this great basin one must rely in part, at least, on inference based on the known orogenic history of the Texas region. It has elsewhere been shown that throughout much, if not all, of Paleozoic time a land mass existed in the present Gulf Coastal Plain probably extending southwestward into northern

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[116]Gould, C. N., and Lewis, Frank E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol Surv., Circ. 13. p. 10, 1926

[117]Among publications relating to structural features in the Permian basin cited in the bibliography of Vol. I are the following: Ackers, 1; Adams, 8; Adkins. 12; Bybee, 190; Bybee, Boehms, Butcher, and Hemphill, 190a; Bybee, Hemphill, and Boehms, 190b; Cartwright, 200 and 201; Case, 221b; Dodson, 432b; Dunbar, 510d; Gester and Hawley, 577; Hailton, 653; Hennen, 706; Hennen and Metcalf, 707; Jones and Conkling, 882; Liddle and Prettyman, 991; Lowman, 1020; Metcalf, 1104; Rettger, Carsey, and Morero, 1301b; Sellards, Bybee, and Hemphill, 1428; Sellards and Patton, 1414; Sellards and Schoch, 1418; Sellards and Williams. 1421; Willis. 1763, 1764, and 1765.

Mexico. The history of Central Texas shows that through successive orogenies this land mass crowded westward obliterating old and forming new basins of deposition. Of the seas which lay west and northwest of the Paleozoic land mass, that of Lower Ordovician time is known to have extended across what is now the southern end of the Permian basin, Lower Ordovician marine limestones having been drilled into in Reagan and Crockett counties. It is probable that the Cambrian seas had a similar extent. The basin of deposition of the Paleozoic seas up to and including Lower Pennsylvanian, however, does not coincide with the present Permian basin but was rather in basins lying closer to and controlled by the land mass of the Gulf Coastal Plain and of northern Mexico.

On the other hand, Strawn sediments are known in Pecos, Crane, Fisher, and Cottle counties. On the evidence now available it seems probable that the Permian basin may have been initiated approximately in its present form near or somewhat later than mid-Pennsylvanian time, when following extensive orogenies the Pennsylvanian and Permian seas spread across a vast region in Texas, New Mexico, Oklahoma, Kansas, and Nebraska.

Sediments of Upper Pennsylvanian time in the basin lie approximately, if not actually, concordant with the Permian sediments indicating that the basin originated early enough to receive late Pennsylvanian sediments and subsided gradually through Permian time. Consistent with this interpretation is the fact that the Upper Pennsylvanian and Permian strata dip into the basin at the east, south, and west sides.

The basin was partly filled during Permian time. However, that it continued as a basin into Mesozoic time is shown by the accumulation of 1000 or 1800 feet of nonmarine Triassic sediments unconformably overlying the Permian. The Triassic sediments rest with angular unconformity on the Permian, indicating further downwarping during the interval between Permian and Triassic as well as in post-Triassic time. In later time the entire region was largely, if not entirely, covered by Cretaceous seas, the Cretaceous deposits over the High Plains now persisting merely as remnants. Nonmarine Cenozoic deposits overlie the basin in the High Plains region of Texas and New Mexico.

The Permian basin is a great regional depression but is by no means so simple in its structural features as was assumed when the basin was less well known. On the contrary, very pronounced uplifts occur within the basin. Of these uplifts, the Amarillo Mountains lying in the northern Panhandle region have already been described. These mountains trend approximately east-west and hence directly across the basin, partially dividing it into northern and southern sub-basins. Eastward, as already shown, the Amarillo Mountains connect with the Wichita chain, and westward they trend towards the New Mexico plateau of pre-Cambrian rocks. The time of principal uplift of the Amarillo Mountains is believed to be mid-Pennsylvanian so that they are older than the basin in its present form. That the Upper Pennsylvanian seas lapped against the sides of these mountains is proven by the presence in the formations of wedges of arkosic materials derived from the mountains. The complete submergence of the mountains came about through increased flooding by the seas, increased depression of the basin, and reduced elevation of the mountains by erosion. All three factors may have operated to submerge the mountains. By early Permian time the mountains were largely submerged or engulfed by sediments.

Other mountain uplifts, if there are such, underlying the northern part of the Texas High Plains, remain to be discovered as this great region is more fully explored by drill or by geophysical methods. The complete blanketing of the surface with level lying sediments makes the detection of the buried structural features particularly difficult.

CENTRAL BASIN PLATFORM OR PECOS UPLIFT

In the southern part of the Permian basin is an uplift to which Cartwright[118] in 1930 applied the name Central Basin Platform. The term Pecos uplift has been used in Volume I, page 52.

The strike of the Central Basin Platform is approximately north-south or north-northwest to south-southeast. Instead of being a chain of mountains with successive peaks, as in the Amarillo uplift, it apparently is a platform having a width of 30 or 35 miles and extending not less than 150 miles in a north-northwest to south-southeast direction in New Mexico and Texas. Contoured on the Permian limestones, the platform is found to have elevated east and west margins and a depressed center. This feature of elevated margins is

[118]Cartwright, L. D., Jr., Transverse section of Permian basin, west Texas and southeast New Mexico: Bull. Amer. Assoc. Petr. Geol., vol. 14, p. 970, 1930.

possibly depositional rather than structural. From Lea County in southeastern New Mexico this platform or uplift extends southward through western Andrews, eastern Winkler, eastern Ward, western Crane, southwestern Upton, and eastern Pecos counties. Many of the oil fields of this part of the state and of New Mexico lie on the east and west margins of this platform. In New Mexico the platform, or at least the deposits of limestone which overlie the platform, according to Bybee,[119] curves westward through Eddy County, there meeting and merging with the Guadalupe Mountains.

This platform divides the southern Permian basin into two subbasins. That lying west of the platform is most commonly known as the Delaware Mountain basin, this name being derived from the great thickness of the Delaware Mountain formation in this basin.[120] The name Toyah basin was applied much earlier to a part of the Pecos Valley in Texas.[121] However, the Toyah basin as a surface feature does not in all respects coincide with the Delaware Mountain basin which is a buried structural feature. The structural basin east of the uplift commonly referred to as the main Permian Salt basin may appropriately be known as the Midland basin.

The foundation rocks underlying the Pecos uplift are imperfectly known. Near the west margin of the uplift in northern Pecos County a well has been drilled to altered, possibly pre-Cambrian, rock which is reached at this locality at the moderate depth of 4750 feet. The formations resting on the altered rock are either late Pennsylvanian or Permian in age.[122]

A well drilled by the Humble Oil and Refining Company on the White and Baker ranch near the southeastern limits of the platform passed from Pennsylvanian to Middle Ordovician (Simpson) at or near depth 8012 feet. Lower Ordovician (Ellenburger) was reached

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[119]Bybee, H. P., Some major structural features of west Texas: Univ. Texas Bull. 3101, pp. 19–26, 1931.

[120]Willis, Robin, *Structural development and oil accumulation in Texas Permian*: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 1033–1043, 1929.

[121]Hill, R. T., Physical geography of the Texas region: U. S. Geol. Surv., Topo. Atlas, folio (No. 3), 12 pp., 1900.

[122]The reasons for regarding the rock in which this well terminated as probably pre-Cambrian in age have been given in Volume I, page 53. The well was drilled by the Shell Petroleum Corporation on land owned by The University of Texas.

in this well at or near depth 9385 feet. The well has been abandoned in Ellenburger at depth 9811 feet.*

Near the east margin of the platform in Upton County a well completed during 1935, the Gulf McElroy No.103, reached the depth of 12,786 feet. In this well the base of the Permian is placed on the evidence of fusulinid fossils at about 7493 feet.[123] Of the great number of wells drilled in the oil fields on this platform and as test wells for oil, all with the exception of these three terminated before reaching the base of the Permian sediments. Fossils obtained from the McElroy well at depth 9462 feet, according to P. V. Roundy, are Lower Pennsylvanian in age, and others at depth 10,581 to 10,590 feet, according to G. H. Girty, are either Lower Pennsylvanian or Mississippian, probably Pennsylvanian. (Letters of November 2, 1934, and January 16, 1935.) The Ellenburger, Lower Ordovician, was reached at or near depth 12,391 feet.†

Dr. H. P. Bybee[124] states that cores obtained by him from wells at the west margin of this platform contain evidence of faulting. The east margin may or may not be a fault scarp. It is much less regular than is the west margin.

While there has been extensive drilling on this platform but little is known, as already indicated, of the foundation conditions. The early Paleozoic history of the region is unknown on any basis other than inference drawn from the available data on the regional geologic history. The geologic and tectonic history of the region as a whole leads one to infer that the early Paleozoic seas probably spread across at least the southern or Texas part, or possibly all, of this now uplifted platform (Vol. I, p. 81). The absence of pre-Upper Pennsylvanian formations at the west margin of the uplift in Pecos County leads to the further inference that erosion occurred in pre-Upper Pennsylvanian time sufficient to expose the pre-Cambrian rocks at this locality. The greater thickness of Pennsylvanian and the much greater depth to the base of the Pennsylvanian in southern Pecos and eastern Crane counties indicates that the great block plunges southward and is tilted eastward.

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*For additional data on formations penetrated by this well, see "Unconformities in the Humble White and Baker deep test, Pecos County, Texas," by J. Ben Carsey, Univ. Texas Bull. 3501, 1935.

[123]Hemphill, H. A., and Gile, R. E. The Simpson (Ordovician) was recognized in this well a* or near depth 11,400 feet.

†Martin, B. G , and Mills, Brad, World's deepest test: *Oil Weekly*, p. 66, July 1, 1935.

[124]Personal statement, November, 1933.

By analogy with other known regions it is permissible to entertain the hypothesis that uplift in this region occurred in Pennsylvanian time and after erosion had occurred sufficient to remove all Paleozoic rocks from a part of its west margin, this block was resubmerged in late Pennsylvanian or Permian time. This hypothecated history of the uplift is based, except as otherwise indicated, on inference and analogy with other known uplifts and should be so understood. Under this interpretation the early Paleozoic sediments should be present on the uplift in Texas except where removed by pre-Upper Pennsylvanian erosion. Unfortunately the amount of erosion on the platform is unknown except as inferred from the one well drilled at the west margin of the uplift. The original block was tilted and thus preserved Paleozoic rocks, including Pennsylvanian, on the east and south margins which have been eroded from a part or all of the west margin. The Bend is absent so far as known at the south margin (Baker well) presumably by pre-Strawn erosion as on the Reagan uplift.

That structural conditions in some degree controlled depositional facies in the Permian seas is becoming increasingly evident. On this platform, as demonstrated by Gulf Company No. 103 McElroy well recently drilled, is approximately 4800 feet of limestone, the stratigraphic equivalent of which in the basin east of the uplift is in part shale or shale intermixed with thin limestone strata. The probable explanation is that a structurally high ridge in early Permian time, occupying the place of the present platform, resulted in clear waters in which limestone, in part of reef facies, accumulated. In the basin at the east during the same time interval a great body of sediments, chiefly dark shales and thin limestones, accumulated. Eastward these shales, or a large part of them, again grade into limestones at and near the outcrop of the formations on the east rim of the basin. The shales of the main Salt or Midland basin could not have entered the basin across the limestone depositing areas at its east or west sides and must accordingly have entered from the north or from the south. The Permian seas extended so far to the north through Texas and to the northwest through New Mexico that it does not seem probable that the shales could have been carried in from that direction. A much more probable source is from the south where, in the Texas Gulf Coastal Plain of the Rio Grande region

Eastern margin of Marathon basin showing angular unconformity between steeply-dipping Paleozoic and nearly horizontal Cretaceous formations. South side of Housetop Mountain, 20 miles east of Marathon. Photograph by C. L. Baker.

and in northern Mexico, the land mass Llanoria was possibly still yielding sediments which were carried into this basin by northward flowing streams.[125] In Pennsylvanian time the Llanoria or Columbia land mass in Mexico was being actively eroded as shown by the thick accumulation of clastic sediments in the Marathon region. That the sediments of this Permian basin should be relatively fine is consistent both with the considerable distance from this land mass as a source and with the possibly reduced elevation of the mountains by Permian time.

The later history of the Central Basin Platform, according to the studies of H. P. Bybee and associates, includes successive mild uplifts in Permian and perhaps in later time.

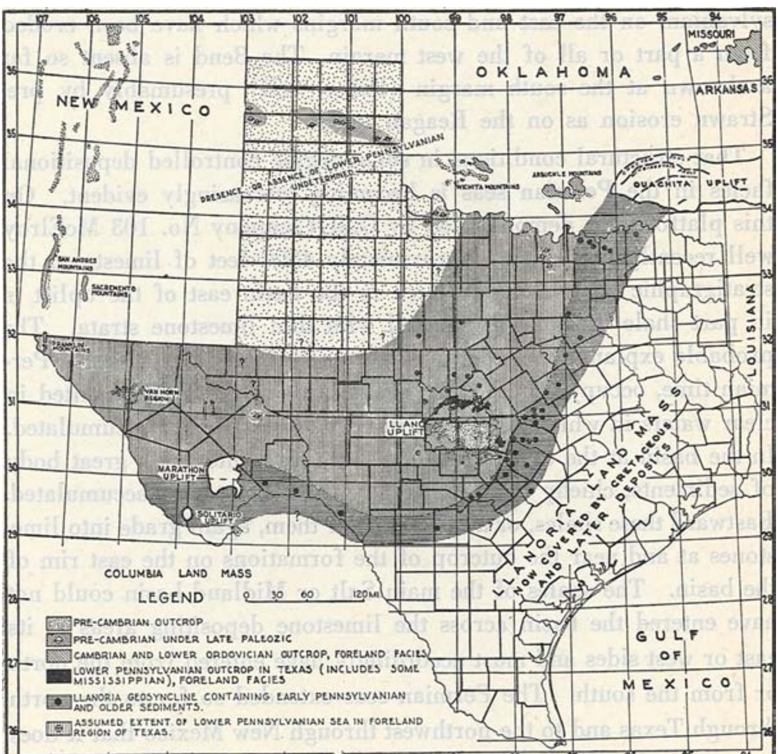

Fig. 8. Map showing probable extent of Lower Pennsylvanian sea in Texas.

[125]Dr. J. W. Beede, in manuscript, has postulated a southern source for these shales.

REAGAN UPLIFT

In view of the meager information as to the early history of the Central Basin Platform it is refreshing to have at hand some further information on a smaller uplift in the main Salt basin. The uplift referred to is that on which the Big Lake, Powell, and some smaller oil fields are located, here named the Reagan uplift. This uplift is now known to extend through Reagan County and into Crockett County, a distance of about 50 miles. Its trend, like that of the Central Basin Platform, is north-northwest to south-southeast. On this uplift several wells have been drilled to the Lower Ordovician, and oil is produced at several horizons.

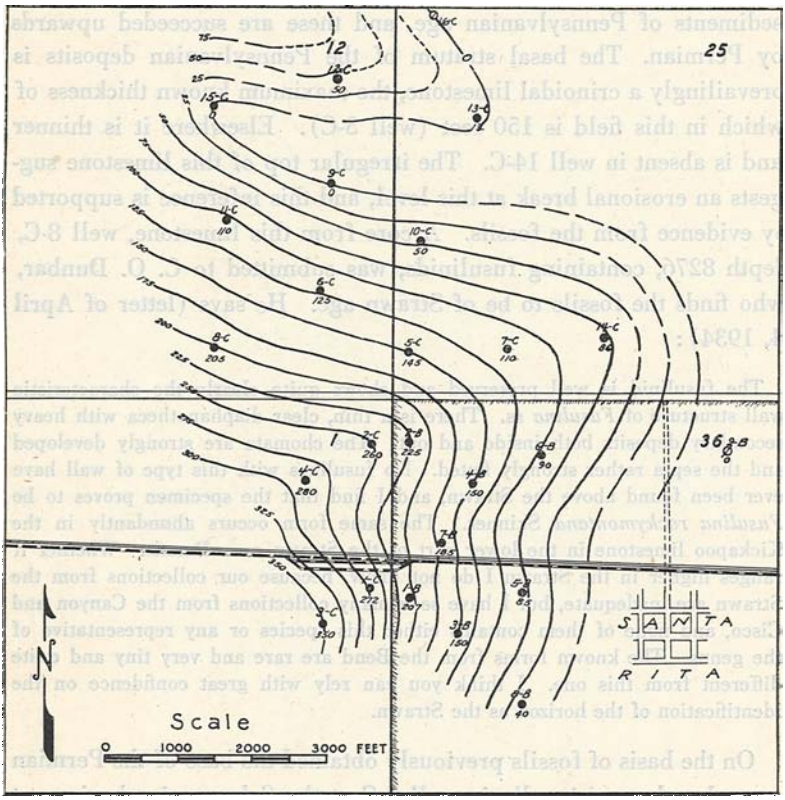

Fig. 9. Thickness map of the Simpson formation in the Big Lake oil field of Reagan County. Contributed by H. P. Bybee. Contour interval 25 feet.

In the Ordovician strata the uplift, in so far as it is known at that level, is found to be very sharp. The trend is north-northwest to south-southeast. The structural feature, in the Big Lake oil field, contoured on the Lower Ordovician, is narrow, and the dip from the crest southwestward in the Ordovician strata is at the rate of about 800 feet per mile. The dip eastward from the crest, although rapid, is not fully determined. The structure in the Lower Ordovician is thus a sharply folded anticline. Middle Ordovician strata, Simpson or Chazy series, which overlie the Lower Ordovician, have been removed at some localities by pre-Strawn (Pennsylvanian) erosion. The Simpson deposits are probably in structural agreement with the Lower Ordovician.

Resting on the Ordovician strata with angular unconformity are sediments of Pennsylvanian age, and these are succeeded upwards by Permian. The basal stratum of the Pennsylvanian deposits is prevailingly a crinoidal limestone, the maximum known thickness of which in this field is 150 feet (well 3-C). Elsewhere it is thinner and is absent in well 14-C. The irregular top of this limestone suggests an erosional break at this level, and this inference is supported by evidence from the fossils. A core from this limestone, well 8-C, depth 8276, containing fusulinids, was submitted to C. O. Dunbar, who finds the fossils to be of Strawn age. He says (letter of April 4, 1934):

> The fusulinid is well preserved and shows quite clearly the characteristic wall structure of *Fusulina* ss. There is a thin, clear diaphanotheca with heavy secondary deposits both inside and out. The chomata are strongly developed and the septa rather strongly fluted. No fusulines with this type of wall have ever been found above the Strawn, and I find that the specimen proves to be *Fusulina rockymontana* Skinner. The same form occurs abundantly in the Kickapoo limestone in the lower part of the Strawn near Dennis. Whether it ranges higher in the Strawn I do not know, because our collections from the Strawn are inadequate, but I have seen many collections from the Canyon and Cisco, and none of them contains either this species or any representative of the genus. The known forms from the Bend are rare and very tiny and quite different from this one. I think you can rely with great confidence on the identification of the horizon as the Strawn.

On the basis of fossils previously obtained the base of the Permian was placed provisionally in well 1-C at the *Schwagerina* horizon at and near depth 7700 feet (Vol. I, p. 182). The crinoidal limestone of Strawn age is reached in this well at depth 8270. The intervening 570 feet is undetermined as to age but is either Permian in part or wholly, or Pennsylvanian later than the Strawn crinoidal limestone.

The Big Lake structural feature, contoured at the top of the Permian "big lime," about 5000 feet above the top of the Ordovician, presents an appreciably different appearance to that known in the Ordovician or in the Strawn Pennsylvanian strata. At the "big lime" level, 3000 to 3100 feet below the surface, there is found an irregular dome with closure of 250 or more feet, the center of which is somewhat west of the anticline in the Ordovician strata.

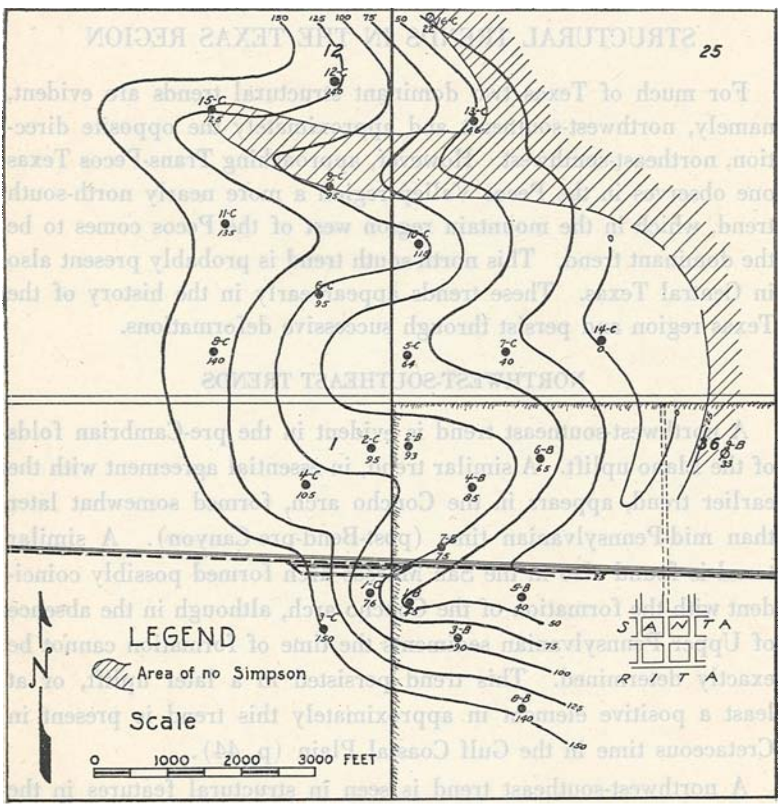

Fig. 10. Thickness map of crinoidal limestone of Strawn age in the Big Lake oil field of Reagan County. Contributed by H. P. Bybee. Contour interval 25 feet.

An erosional unconformity in the Pennsylvanian above the "crinoidal" limestone is probable, although possibly not fully demonstrated. The dome is elongated northwest-southeast. A northeast-southwest trend is likewise evident. Until the deep formations are better known, the relationship of the structural features in the earlier and later formations cannot be fully given. That the folding is much more intense in the Ordovician than in the late Pennsylvanian and Permian is, however, obvious. The history of the uplift, accordingly, is that of pronounced uplift and intense erosion in pre-Upper Pennsylvanian time with only mild folding in later time. In this respect this structural feature is in agreement with most other of the major structural features of Central Texas.

STRUCTURAL TRENDS IN THE TEXAS REGION

For much of Texas two dominant structural trends are evident, namely, northwest-southeast and approximately the opposite direction, northeast-southwest. However, approaching Trans-Pecos Texas one observes in the Pecos Valley region a more nearly north-south trend, which in the mountain region west of the Pecos comes to be the dominant trend. This north-south trend is probably present also in Central Texas. These trends appear early in the history of the Texas region and persist through successive deformations.

NORTHWEST-SOUTHEAST TRENDS

A northwest-southeast trend is evident in the pre-Cambrian folds of the Llano uplift. A similar trend, in essential agreement with the earlier trend, appears in the Concho arch, formed somewhat later than mid-Pennsylvanian time (post-Bend-pre-Canyon). A similar trend is found also in the San Marcos arch formed possibly coincident with the formation of the Concho arch, although in the absence of Upper Pennsylvanian sediments the time of formation cannot be exactly determined. This trend persisted in a later uplift, or at least a positive element in approximately this trend is present in Cretaceous time in the Gulf Coastal Plain (p. 44).

A northwest-southeast trend is seen in structural features in the Red River region of southern Oklahoma and northern Texas. In this region uplifts with this trend occurred from as early as Lower

Pennsylvanian, the first known uplift of the Criner Hills, to as late at least as post-Cretaceous. Among the structural features in this region in which this trend may be seen are the buried Amarillo Mountains; the Red River uplift, including the Muenster and Electra arches; the Wichita and Arbuckle mountains; the Criner Hills and numerous buried structural features in southern Oklahoma revealed by drilling, many of which are oil producing. Among structural features in southern Oklahoma originating in Pennsylvanian time and having a northwest-southeast trend are the following: Duncan, Loco, Healdton, Hewitt, Oscar, Cement, Knox, Velma, Graham, Caddo, Timbered Hills, Dougherty, and Tishomingo.[126]

That movement occurred on the same structural trend in Texas in post-Cretaceous time is well shown by the Preston anticline which extends from Marshall County, Oklahoma, through Grayson and Fannin counties, Texas. In part this anticline may be explained by depositional dip of Cretaceous formations across a structural, and probably also topographic, high of that time, namely, the Criner Hills uplift upon which it is apparently superimposed at least in Oklahoma. Compacting of sediments, likewise, would increase the dips from topographic highs. However, the amount of structural relief in the strata in this anticline is large, 700 or 800 feet, and the rate of dip at the west side of the anticline in Texas reaches a maximum of 400 feet or more per mile. This belt of high dipping strata in Texas was interpreted by Hill[127] as a line of faulting, and it seems probable that some faulting is present.

Paralleling the Preston anticline are several associated synclines and anticlines. Immediately south of the anticline in Texas is a syncline named the Sherman syncline by Hopkins, Powers, and Robinson.[128] This syncline is very well developed south of the Criner Hills in Oklahoma and has been named the Marietta syncline by Bullard.[129] Smaller structural features of this trend in the Cre-

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[126]Tomlinson, C. W., The Pennsylvanian system in the Ardmore basin: Oklahoma Geol. Surv., Bull. 46, fig. 2, p. 23, 1929.

[127]Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Surv., 21st Ann. Rept., pt. 7, p. 614, 1901.

[128]Hopkins, O. B., Powers, Sidney, and Robinson, H. M., The structure of the Madill-Denison area, Oklahoma and Texas, with notes on oil and gas development: U. S. Geol. Surv., Bull. 736, p. 8, 1922.

[129]Bullard, F. M., Geology of Love County, Oklahoma: *Oklahoma Geol. Surv., Bull.* 33, p. 45, 1925.

taceous strata in Oklahoma are the Oakland and Madill anticlines and the Kingston and Cumberland synclines.[130]

The trend of the Amarillo Mountain chain as a whole lacks but little being east-west. The trend of its component parts, however, is more nearly northwest-southeast. The faults in the Amarillo Mountains, likewise, mostly trend northwest-southeast. The Electra arch of the Red River uplift, likewise, as a mountain chain extends nearly due east-west. Drilling on this concealed chain of mountains has not been sufficient to develop the structural details. However, it may confidently be expected, and there is some evidence to show, that within the chain the structural elements trend northwest-southeast. Northwest-southeast trends are seen in the region of the Sabine uplift in Louisiana and Texas as well as in the Monroe uplift which parallels the Sabine uplift in Louisiana.

NORTHEAST-SOUTHWEST TRENDS

Northeast-southwest trends come into Texas from the Ouachita Mountains of Oklahoma where they are well developed in overthrust faults and folds of the Appalachian type. In Texas these structural features are concealed, as previously stated, by a covering of Cretaceous except in the Marathon and Solitario regions of west Texas where the same type of thrusting and folding is revealed by the removal of the Cretaceous blanket from these two domes. Folding with this trend is believed to have taken place in the Marathon region as early as mid-Pennsylvanian, the Haymond formation, and to have been renewed with great overthrusting in late Pennsylvanian. Folding with northeast-southwest trend is present in the Carrizo Mountain formation underlying the Van Horn sandstone in the Van Horn region and hence is presumably of pre-Cambrian age.

An extensive series of faults with northeast-southwest trend is found in the Llano uplift. These faults have been discussed on an earlier page under the term of Llano fault system (p. 85). These faults were formed in post-Bend time and previous to, or in part during, Strawn time. The Bend arch is not entirely in agreement with the trend of the faults of the Llano system, and this structural feature may be independent of that system as maintained by Cheney

[130]Bullard, F. M., *op. cit.*, p. 52.

(p. 92). The Permian basin trends north-northeast, thus approximately paralleling the trend of the Bend arch, and is the resultant of forces which acted in late Paleozoic time.

The extensive faulting of the Gulf Coastal Plain varies from north-northeast to east-west or nearly so. In the Balcones zone the faulting and folding are north-northeast, and this direction persists for individual faults and folds notwithstanding that the trend of the fault zone as a whole varies from north-south to east-west. That is, the trend of the zone varies, but the structural trend persists with but little variation. In the Mexia zone a variation in the trend of the faults is observed from north-northeast in the southern part of the zone to nearly east-west around the east Texas embayment. Other faults of the Coastal Plains, likewise, vary in such manner as to tend to parallel the Gulf Coast shore line. The position of the Gulf of Mexico and of the Gulf Coastal Plain sediments seemingly controls the trend of these faults. The faults nearest the present Gulf closely parallel the present Gulf shore line. Faults more remote from the Gulf Coast, as the Balcones zone, do not parallel the present coast line but more nearly parallel an earlier coast line as, for instance, that of early Eocene time.

NORTH-SOUTH TRENDS

A north-south trend is prevalent in Trans-Pecos Texas. In the southern part of the Trans-Pecos region and in Mexico the trend shifts to south-southeast. Much of the faulting in this region with prevailing north-south trend is relatively late, possibly Pliocene (p. 31). That some structural features of this trend antedate Upper Pennsylvanian is proven by the Reagan uplift in which a north-south or north-northwest trend is observed in an anticline or fault block which existed as such previous to the deposition of the overlying Pennsylvanian and Permian sediments (p. 111). Renewal of activities of the forces resulting in north-northwest trends in post-Permian-pre-Cretaceous time is proven by the further folding in this uplift involving Upper Pennsylvanian and Permian sediments. The Pecos uplift or Central Basin Platform having this trend likewise involves Permian sediments and is chiefly, although not necessarily entirely, of pre-Cretaceous origin.

In the Rio Grande region of the Texas Coastal Plain, Barton detects in the drainage pattern three fracture systems as follows: north-south, northeast-southwest, and northwest-southeast. Of these systems the north-south is the more prevalent on the Reynosa Plain. The three trends are recognized crossing the Piedras Pintas and Palangana salt domes (Bull. Amer. Assoc. Petr. Geol., vol. 17, pp. 1194–1212, 1933).

TRENDS AS DETERMINED FROM JOINT SYSTEMS

Dr. F. A. Melton has contributed the following statement of fracture systems in Central Texas based chiefly on a study of jointing.

FRACTURE SYSTEMS IN CENTRAL TEXAS

F. A. MELTON[131]

The study of joints in sedimentary rock was undertaken with the hope of finding evidence bearing on the relative age of the Ouachita and Arbuckle mountains. Partial results of this study have been published.[132] It was found that in strata of Pennsylvanian and Permian age, throughout areas of large size in Oklahoma, there exist systems of joints with fairly constant strike. It thus became a matter of importance to determine whether or not a systematic arrangement of joints is to be found elsewhere in flat-lying Carboniferous beds. Accordingly, the investigation was extended into north-central Texas, eastern Kansas, southern Missouri, and western Arkansas.[133] Later, with the help of the National Research Council, it was continued in the frontal zone of the Appalachian Mountains and around the Nashville Dome in Tennessee and northern Alabama.

It was soon discovered that only in relatively hard beds are joints systematic enough to merit study. Plastic shales are in some places not jointed, and where there are fractures it is difficult to distinguish between those due to weathering, slumping, etc., and those caused by crustal movements.

Since joints are usually perpendicular to the stratification of horizontal beds, they are quite uniformly vertical. Near faults, on the other hand, joints often depart strongly from the vertical as also do the faults themselves. In the plains, joints are so much more numerous than faults that fractures selected at random do not generally show the influence of faulting. The most important aspect of joints in flat, hard strata is thus seen to be their strike.

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[131]The University of Oklahoma.

[132]Melton, F. A., A reconnaissance of the joint-systems in the Ouachita Mountains and central plains of Oklahoma: Jour. Geol., vol. 37, pp. 729–746, 1929; and Age of the Ouachita orogeny and its tectonic effects: Bull. Amer. Assoc. Petr. Geol., vol. 14, pp. 57–72, 1930; and Joint studies in the Southwest and their bearing on tectonic history (abst.): Bull. Geol. Soc. Amer., vol. 42, p. 231, 1931.

[133]The writer is indebted to Mr. R. V. Hollingsworth for making part of the measurements used in this paper.

EXPLANATION OF FREQUENCY DIAGRAMS AND PRESENTATION OF DATA

The "joint rose" is a frequency diagram illustrating the strike of different groups of joints and likewise the relative number of joints in each group. It is used in the nine diagrams of Plate III to represent the joint and fault directions at localities arranged geographically from west to east. Thus Figure 1 illustrates the strike of faults in the Yates oil field of Trans-Pecos Texas, whereas Figure 9, at the opposite end of the series, shows the trend of joint systems in northwestern Arkansas. The other figures present similar data for the localities intermediate between these two.

In Figure 3 the sum of the lengths of all the lines represents 100 per cent of the joints measured at nine different stations in Permian beds near San Angelo. It shows that 45 per cent of all the joints measured have a strike of N. 35° E. to N. 55° E. It likewise shows that 13 per cent of the joints strike N. 75° W. and that 22 per cent range from N. 20° W. to N. 45° W. Furthermore, the diagram proves that no other systems or sets of much importance in respect to number occur at the stations examined. It is also apparent that many directions are represented by only a few joints.[134]

Figure 4 is a joint rose illustrating, in a group of seven stations near Sweetwater, the relative number or percentage of joints having the indicated strike. For example, 37 per cent of the joints strike N. 35° to 45° E., 8 per cent strike N. 5° W., and 32 per cent strike N. 45° to 75° W.

The most important directions and the percentage of joints at each of three localities are given below:

Locality	*Number of stations*	*Plate III*	*Direction*	*Per cent*
Near Breckenridge	12	Fig. 6	North 25°–45° east	42
			North 45°–65° east	34
			North 25° west	8
Near Coleman	8	Fig. 5	North 45°–55° east	28
			North 25°–45° west	25
			North 65° west	5
			East–west±	11
Near Jacksboro	10	Fig. 7	North 25°–45° east	55
			North 35°–55° west	20
			North 65° west	11

In measuring the strike of joints, various local and temporary conditions sometimes affect the nature of the sample which an observer takes at a given outcrop. For example, the extent to which weathering has progressed, the direction and steepness of the surface slope, the nature of the vegetation, the competence of the underlying and supporting beds, and other factors may affect the degree of visibility of joints. A composite diagram was constructed

[134] In this and other subsequent diagrams several very short lines have been omitted. They represent only a few of the joints of apparently random directions.

to eliminate as completely as possible the effects of these varying conditions at the outcrop. It dealt with the number of stations yielding joints of particular strike. This diagram revealed that two main systems of joints exist, the maxima of frequency being N. 40° to 55° E. and N. 40° to 50° W. A subordinate maximum occurred at about 5° west. Even though joints with almost any desired strike may be found, at most of the 95 outcrops thus far examined they are arranged in two definite groups—those striking northeastward and those striking northwestward.

LATERAL EXTENT OF JOINT SYSTEMS

A northwestward-striking system which the writer believes is nearly identical in origin and in age with the one illustrated in Figures 5, 6, and 7, is found in Oklahoma, northern Arkansas, southeastern Kansas, and western Missouri. It spreads like a fan from the front of the Ouachita Mountains. A northwest system very similar in intensity and in its relationship to the mountain front has likewise been found near the Appalachian Mountains in northern Alabama and eastern Tennessee.

Joints and faults possessing a similar northwest trend, yet of different origin and mainly of different age, occur in the Yates oil district of western Texas. Aerial photographs have revealed the trend of the faults, which are found in rocks of the Lower Cretaceous series. The principal directions thus discovered have likewise been found in the joints by a personal examination of outcrops in the Lower Cretaceous and also in the Triassic. These fractures, no doubt, extend downward into the buried Permian strata as well. Figure 1 is a frequency diagram showing the strike of 21 faults visible from the air. Though the writer has not attempted to trace this prominent system of faults toward the east into the Carboniferous rocks of north-central Texas, such examinations as have been made strongly suggest that it continues as far as San Angelo, though with a slightly changed direction (cf. fig. 3).

One hundred miles north-northwest of the Yates district in the oil fields of southeastern New Mexico an aerial exploration resulted in the discovery of a pronounced alignment of sink-holes extending in nearly straight lines for several miles. They doubtless reveal the presence and direction of prominent zones of joints or of faults in the limestone which underlies the surficial rocks of that region. A statistical analysis of the direction of 33 of these lines is given in Figure 2. The direction occurring most frequently is between N. 60° and 70° W. The northeastward-striking fractures seem to be relatively insignificant, thus presenting a strong contrast with the conditions in north-central Texas.

ORIGIN OF THE JOINTS

It is necessary to proceed with caution in discussing the origin of joints illustrated in the foregoing figures, because fractures of widely different nature, both in regard to controlling conditions and to time of occurrence, may appear much the same on the weathered outcrop. Since the localities examined are scattered sparsely over a large region, the studies thus far undertaken obviously do not extend beyond the reconnaissance stage. Moreover, the data presented are only a small part of all that is available. Other factors sometimes combine with those just mentioned to increase the hazards of speculation regarding origin.

While almost any desired strike may be found in the Carboniferous rocks of northern Texas, a great majority of the fractures follow certain directions. There undoubtedly exist two somewhat complex major systems striking northeastward and northwestward. Likewise there are several "sets" or "trends" of joints which are quite constant in direction for more than fifty miles. The arrangement is not so uniform, however, as in the plains of Kansas and Oklahoma, where one set (N. 75° ± E.) is present over a belt three hundred miles in width, from Kansas City to Oklahoma City, in rocks of Pennsylvanian and lower Permian age.

JOINTS STRIKING NORTHWESTWARD

The northwestward-striking system near Jacksboro and Breckenridge, Texas, in general appearance and in number of joints per unit of length at right angles to their strike (in "intensity"), is nearly identical to a fan-shaped system found in the Ouachita Mountains and their bordering plains in central Oklahoma. In both regions this system becomes more intense toward the southeast, and, furthermore, in Oklahoma it seems to have an unmistakable genetic connection with the movements which formed the mountains. In 1930, before the Geological Society of America, the writer pointed out the strong resemblance between these two northwestward-striking systems in Oklahoma and Texas and suggested that buried mountains of the Ouachita type may exist to the southeastward beneath the coastal plain cover. The connection of this joint system in the Carboniferous strata, with movements of pre-Cretaceous age, is proved by the fact that rocks of the Comanche series, which occur to the eastward of the region under discussion, are not jointed in a comparable fashion.

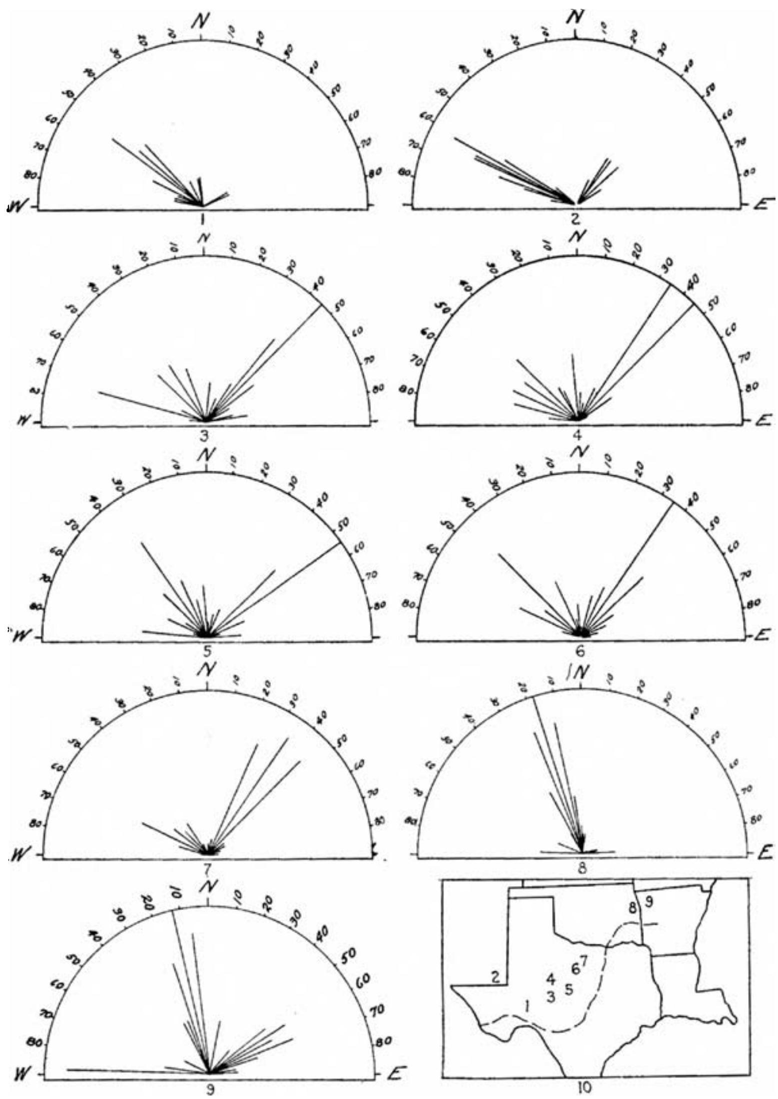
Figure 3 demonstrates the existence near San Angelo of a set of joints, striking N. 75° W., which is not duplicated in the other diagrams illustrating the conditions in north-central Texas. This set is believed to be of later age than the other systems of the region because, in the first place, it possesses a unique prominence near San Angelo, and, in the second place, it appears to be represented by the important sets of joints with similar trend farther west in Texas and New Mexico where they cut rocks of Lower Cretaceous age.

JOINTS STRIKING NORTHEASTWARD

The northeastward-striking joints in the plains of Oklahoma and Kansas are apparently of different age and likewise of a different origin from the northwest systems. In Texas, however, the evidence is not clear on these points. The geological setting suggests two possibilities as to origin, one of which is similar to conclusions previously reached in Oklahoma and Arkansas.

I. This possibility is best illustrated by a comparison of Figures 8 and 9. Figure 9 demonstrates the existence in flat beds of the Ozark plateau in western Arkansas of a joint system, striking N. 55° to 75° E., which may possibly be correlated with the northeast system in Texas the origin of which

The University of Texas Bulletin 3401 **Plate III**



Diagrammatic representation of prevailing strike of joint systems in Texas and adjacent parts of Oklahoma and Arkansas. The sum of the lengths of all the lines in each diagram represents 100 per cent of the measurements at that locality.

Explanation of Plate III

1. Strike of 21 faults which cut Lower Cretaceous strata of the Yates oil district in western Texas. Data secured during an aerial investigation.
2. Strike of 33 joint-zones or faults cutting Permian strata near the southeastern corner of New Mexico. The "faults" are revealed by an unusually straight alignment of sink holes. Data secured during an aerial investigation.
3. Strike of joints measured at 9 different localities in Permian beds near San Angelo.
4. Group of 7 localities near Sweetwater.
5. Strike of joints measured at 8 localities in rock of Permian and Pennsylvanian age near Coleman.
6. Strike of joints measured at 12 localities near Breckenridge.
7. Strike of joints measured at 10 localities in Pennsylvanian rock near Jacksboro.
8. Joint systems of folded Pennsylvanian rock at the northern margin of the Ouachita Mountains, Oklahoma. East-west and north-northwest trends.
9. Joint systems in Pennsylvanian rock of northwestern Arkansas. East-west, north-northwest. and east-northeast trends.
10. Sketch to indicate localities studied and their relation to Ouachita thrust zone.

is under consideration. Also, two other systems are shown, namely, (1) an east-west system parallel to the Ouachita mountain front, and (2) a system striking N. 5° to 20° W.

Farther south rocks of approximately the same age and lithologic nature have been gently folded at the northern margin of the Ouachita Mountains. The general relationships of the joints in this zone of folding are shown by Figure 8.[135] It is apparent that the groups striking N. 5° to 25° W., and east-west are almost identical in trend and relative importance to certain systems found in the flat rocks of the plateau, 50 miles farther north. The northeast system which is so prominent in the plateau, however, is entirely absent.

Several explanations could be advanced for this condition, but in view of the large extent of joints with nearly this same strike in northeastern Oklahoma and southeastern Kansas, the writer suggests that one explanation be given preference to all others. In late Permian or Triassic time, after the Ouachita Mountains had ceased their tectonic activity, the northeast joint system arose, probably through regional tilting of the Carboniferous rocks of the plains monocline, or through other gentle regional movements. Flat, brittle strata were jointed in response to these movements, but where the same strata had previously been folded they were no longer sensitive to such gentle tilting. They, therefore, did not fracture in the same fashion and perhaps not at all.

In other words, this view supposes the northeast system in Texas to be the same in age and origin as the northeastward-striking system in Oklahoma and elsewhere. If such is true, this system appears to be of later age than the Ouachita and associated mountain ranges and to have been caused by the gentle regional tilting of the plains monocline. It would, accordingly, be of

[135]While steep dips may be found in the frontal zone of the mountains, the dip at most of the outcrops examined was less than 30°. In the stations used in this comparison, it was not less than 5°.

later age than the northwest joints in Texas, which appear to owe their origin to a pronounced orogenic disturbance.

II. On the other hand, the northeastward-striking system may have had a different origin. The subsidence of the geosyncline of eastern Texas may have been partly responsible for its development, since it seems roughly to extend parallel to the western side of the basin. This possibility is likewise suggested by analogy with a definite set of joints in northeastern Arkansas near and parallel to the down-faulted or down-warped margin of the Mississippi embayment.

The analogy is not complete, however, since in Arkansas the northeast set just mentioned occupies a rather narrow zone in the Paleozoic rocks near the margin of the embayment. In Texas, on the other hand, the northeast system is widespread throughout the Pennsylvanian and Permian terrane east of the high plains. Moreover, the western flank of the Texas geosyncline is probably by no means so sharp a flexure as that in northeastern Arkansas. Notwithstanding these differences, the possibility of a similar origin must be recognized. Even though the system under discussion may be due to such a subsidence, these joints must have been formed in the earliest stages of the movement, since, as previously mentioned, the Lower Cretaceous beds near this area in north-central Texas are for the most part not jointed in a fashion at all comparable with that found in the underlying rocks of Carboniferous age.

PROGRESSIVE DEFORMATION

A study of structural features in the Texas region brings to light numerous instances of progressive deformation of the rocks. This is true to such an extent that one may say that progressive deformation, or more probably successive deformations, of any particular region is the rule rather than the exception. Examples of progressive deformation on a large scale through a long period of time are found in the basins of deposition where shallow water sediments accumulate to a thickness of thousands of feet, the basin having been gradually downwarped as the sediments accumulated. Such a basin is that of the Ouachita Mountains of Oklahoma, which extends into Texas under a Cretaceous covering. In this basin in Oklahoma some 35,000 feet of Paleozoic sediments accumulated. The Marathon basin in Texas received 20,000 feet or more of sediments during the Paleozoic periods. The Coastal Plain affords illustration of subsidence, with fluctuation, through the latter part of Mesozoic and all of Cenozoic time. The thickness of Cretaceous and Cenozoic sediments near the Gulf margin has been estimated at 20,000 or 25,000 feet in Texas and as possibly 30,000 feet in Louisiana.[136]

[136]Barton, D. C., Ritz, C. H., and Hickley, Maude, Gulf Coast geosyncline: Bull Amer. Assoc. Petr. Geol., vol. 17, p. 1449, 1933.

Such basins obviously do not subside continuously but with fluctuations, amounting in some basins to absence of deposition of entire systems. Thus in the Marathon basin no Silurian deposits are known, and presumably that part of the basin available to examination did not receive Silurian sediments, indicating uplift, either continental or local, sufficient to exclude the sea during Silurian time. Moreover, basins may and often do shift in position in successive periods of time. A westward shift of successive basins in the Central Texas region has been several times mentioned in this volume.

Downwarping is thus progressive through long periods of time. Upwarping or uplift may be likewise progressive. An anticline, dome, or mountain range, when closely studied will usually reveal evidence of progressive uplift. Numerous illustrations of successive uplifts are found in Texas, some of which may be mentioned.

The locality in Texas in which structural conditions are known to the greatest depths below the surface is the Big Lake oil field of Reagan County, located on the structural feature elsewhere described as the Reagan uplift. At this locality it is possible to contour the deformation in the rock strata at successive depths from the surface to about 8500 feet. Progressively increased deformation in the older formations is found at this locality as shown by the following records.

The surface formations, which are of Comanche Cretaceous age, dip gently southeast. According to Hennen,[137] a slight folding into an anticline trending northeast-southwest can be detected in these surface formations, amounting to a closure in contouring of about 30 feet. Hennen has made a map showing structural conditions in the salt bearing series of the Permian formations, depth about 1500 feet. At this depth two great unconformities have been passed, one at the base of the Cretaceous and one at the base of the Triassic. It is not surprising, therefore, to find greater deformation at this level and in these older rocks than at the surface. The structural feature at this depth is a dome or anticline having a closure of about 125 feet and a pronounced northwest-southeast trend. The northeast-southwest trend of the surface anticline is present but not pronounced.

[137]Hennen, Ray V., Big Lake oil pool, Reagan County, Texas: Structure of Typical American Oil Fields, Vol. II, pp. 500–531, 1929.

The next level at which a contour map has been made is at the top of the "big lime" series, depth about 3000 feet. At this level, doming is recognized amounting to a closure of about 250 feet. Two trends may be recognized, northwest-southeast and northeast-southwest, the former being the dominant trend (fig. 9). In 1929 Sellards and Patton suggested that an unconformity probably exists within the Permian at the base of the "red bed" series and above the "big lime" series. The greatly increased structural deformation

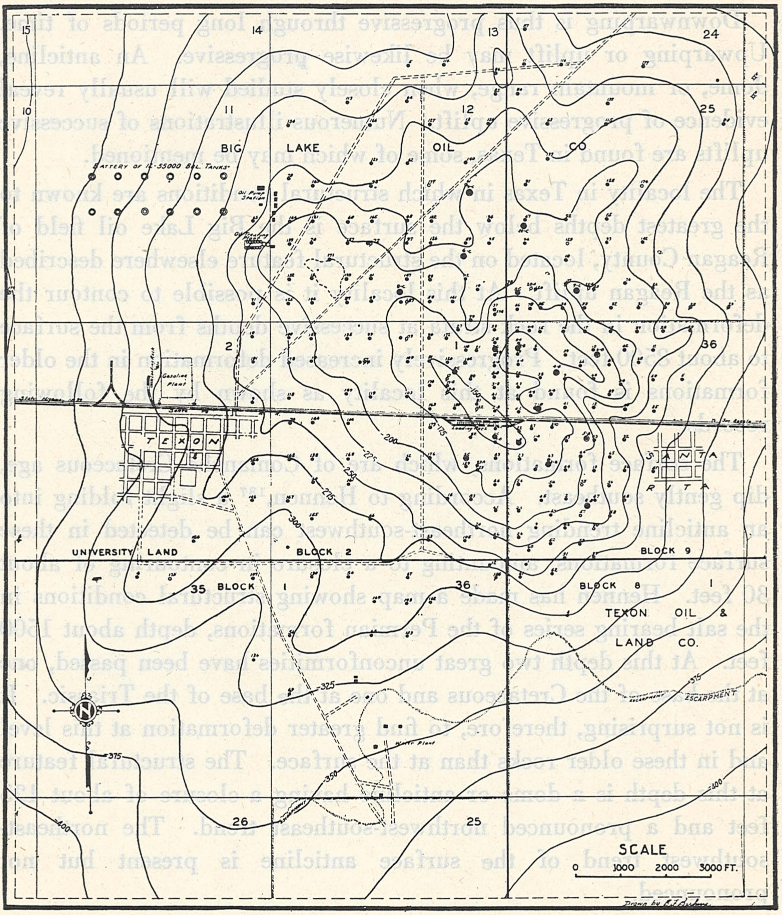


Fig. 11. Contour map in the Big Lake oil field, Reagan County, Texas, on the "big lime," approximately at the 3000 to 3100-foot level.

found at the 3000-foot level, which is below this inferred unconformity, over that found to exist in the salt series lends support to the assumption of an unconformity at the contact of the "big lime" and the overlying "red bed-salt" series.

As a result of the deep drilling of the past few years, it is now possible to contour the top of the Lower Ordovician formations over a small part of the field at a depth of about 8500 feet. To reach this deep horizon a great unconformity is crossed in passing from

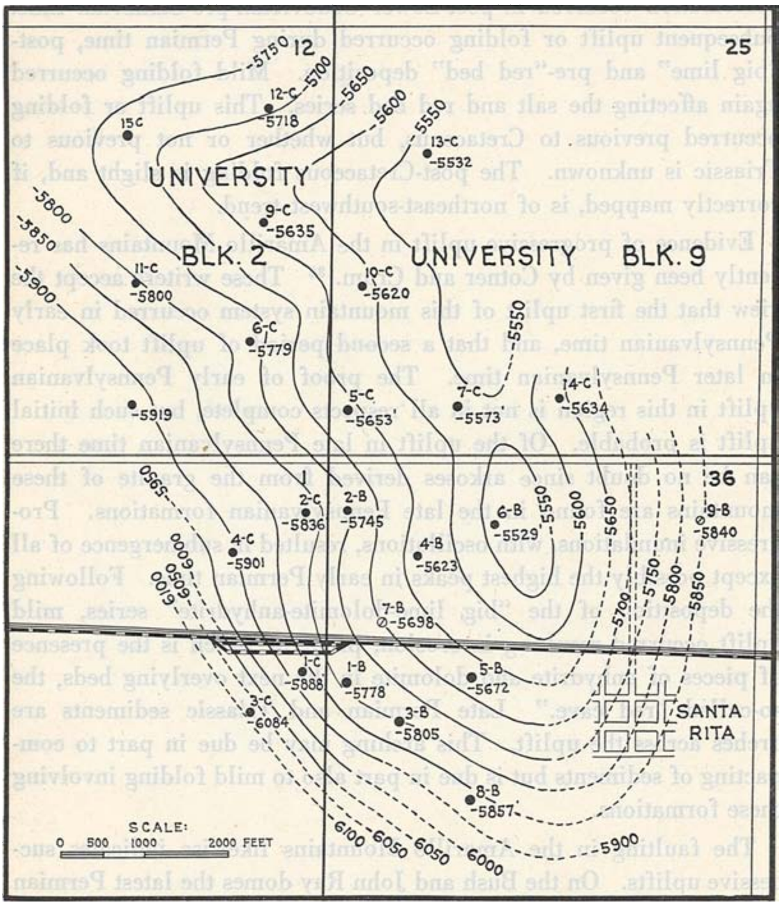


Fig. 12. Contour map on the Lower Ordovician Ellenburger limestone in the Big Lake oil field, Reagan County, Texas, approximately 8200 to 8500-foot level. By H. A. Hemphill, contributed from the geologic division, Survey of University Lands.

late Pennsylvanian or early Permian sediments to Ordovician, the middle and early Pennsylvanian, Mississippian, Devonian, Silurian, and late Ordovician being absent. In the Lower Ordovician rocks in this field, the structural deformation is greatly increased over that found at higher levels. The trend in this anticline is north-south or north-northwest. The opposite trend, northeast-southwest, is possibly present.

Summarizing for this locality, it is shown that pronounced deformation occurred in post-Lower Ordovician-pre-Cambrian time. Subsequent uplift or folding occurred during Permian time, post-"big lime" and pre-"red bed" deposition. Mild folding occurred again affecting the salt and red bed series. This uplift or folding occurred previous to Cretaceous, but whether or not previous to Triassic is unknown. The post-Cretaceous folding is slight and, if correctly mapped, is of northeast-southwest trend.

Evidence of progressive uplift in the Amarillo Mountains has recently been given by Cotner and Crum.[138] These writers accept the view that the first uplift of this mountain system occurred in early Pennsylvanian time, and that a second period of uplift took place in later Pennsylvanian time. The proof of early Pennsylvanian uplift in this region is not in all respects complete, but such initial uplift is probable. Of the uplift in late Pennsylvanian time there can be no doubt since arkoses derived from the granite of these mountains are found in the late Pennsylvanian formations. Progressive inundations, with oscillations, resulted in submergence of all except possibly the highest peaks in early Permian time. Following the deposition of the "big lime-dolomite-anhydrite" series, mild uplift occurred resulting in erosion, proof of which is the presence of pieces of anhydrite and dolomite in the next overlying beds, the so-called "red cave." Late Permian and Triassic sediments are arches across the uplift. This arching may be due in part to compacting of sediments but is due in part also to mild folding involving these formations.

The faulting in the Amarillo Mountains likewise indicates successive uplifts. On the Bush and John Ray domes the latest Permian sediments, Alibates dolomite and associated strata, although folded,

[138]Cotner, Victor, and Crum, H. E., Geology and occurrence of natural gas in Amarillo district, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 17, p. 881, 1933.

afford no proof of having been appreciably faulted. However, underground faulting appears at the west side of the Ray dome in the "salt series" and an even greater displacement occurs in the anhydrite-dolomite series.

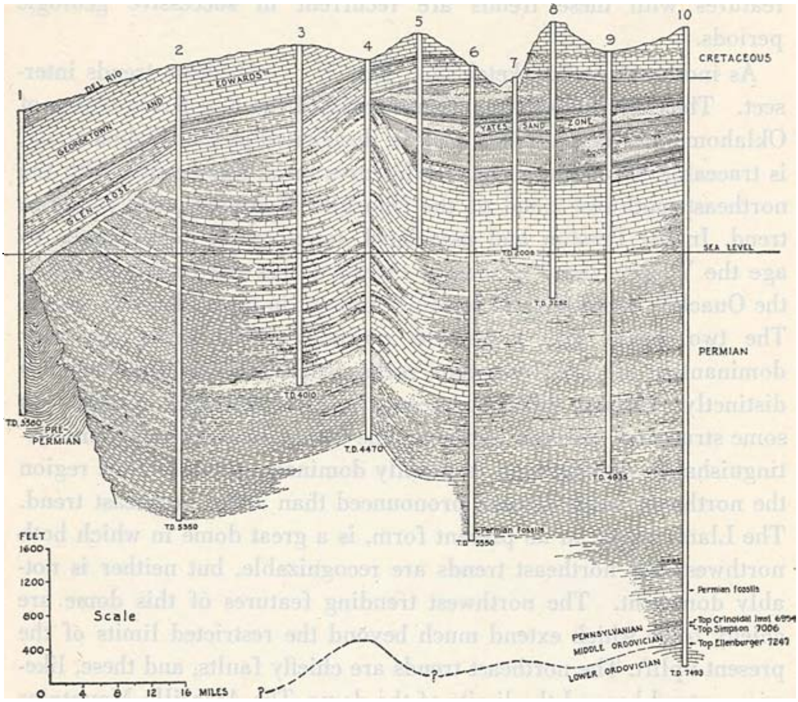


Fig. 13. Sketch illustrating structural conditions in the southern part of the Permian basin of Texas. This sketch has been prepared by H. A. Hemphill as a part of Project 44–33 of the Geological Society of America and is used by permission of the Projects Committee. The wells used in the sketch are as **follows:**

Terrell County

1. Southwest Texas Oil and Gas Assoc., Folsom 1
2. Milham Corp. of Texas, Bassett Mineral Properties 1
3. Sun Oil Co., Scott 1
4. Humble Oil and Refining Co., University of Texas 1
5. Wooley-Jones, Pankenham 1
6. Sides et al., Phelps 1

Crockett County

7. Barbara Oil Co., Cox 1
8. Cooke et al., University of Texas 1
9. Wilcox et al., University of Texas 1
10. Stanolind Oil and Gas Co., Todd 1

PERSISTENCY OF TRENDS

It is not to be assumed that all structural trends in the Texas region can be referred to the three trends mentioned. It does appear, however, that these are the dominant trends and that structural features with these trends are recurrent in successive geologic periods.

As indicated on the sketch map (fig. 1, p. 12), these trends intersect. Thus the northwest-southeast trend of the Red River region of Oklahoma and Texas, which may be designated as the Wichita trend, is traceable in several structural features to its intersection with the northeast-southwest trend of the Ouachita Mountains, the Ouachita trend. In the Preston and associated anticlines of post-Cretaceous age the Wichita trend is seen to extend across the region in which the Ouachita trend is quite certainly present in the underlying strata. The two trends thus cross, the northeast trend being probably dominant in the pre-Cretaceous rocks, while the northwest trend is distinctly dominant in the Cretaceous rocks of the same locality. In some structural features, as the Sabine uplift, the two trends are distinguishable, although one is usually dominant. In the Sabine region the northwest trend is more pronounced than is the northeast trend. The Llano uplift, in its present form, is a great dome in which both northwest and northeast trends are recognizable, but neither is notably dominant. The northwest trending features of this dome are chiefly folds which extend much beyond the restricted limits of the present uplift. The northeast trends are chiefly faults, and these, likewise, extend beyond the limits of the dome. The Amarillo Mountains exhibit the Wichita trend in their northwest trending *en échelon* units and faults, this trend being at right angles or nearly so to the north-northeast trending axis of the basin. The Wichita trend, if it continues into New Mexico, meets the northeast trending Los Animos anticline almost at right angles.

In the southern part of the Permian basin the north-south trending Central Basin Platform trends obliquely across the Permian basin. The Reagan uplift, likewise, trends across the basin. In the Marathon and Solitario uplifts the north-south trends which are dominant in post-Cretaceous structural features meet approximately at right angles the northwest trend which is dominant in the pre-Cretaceous structural features of these uplifts.

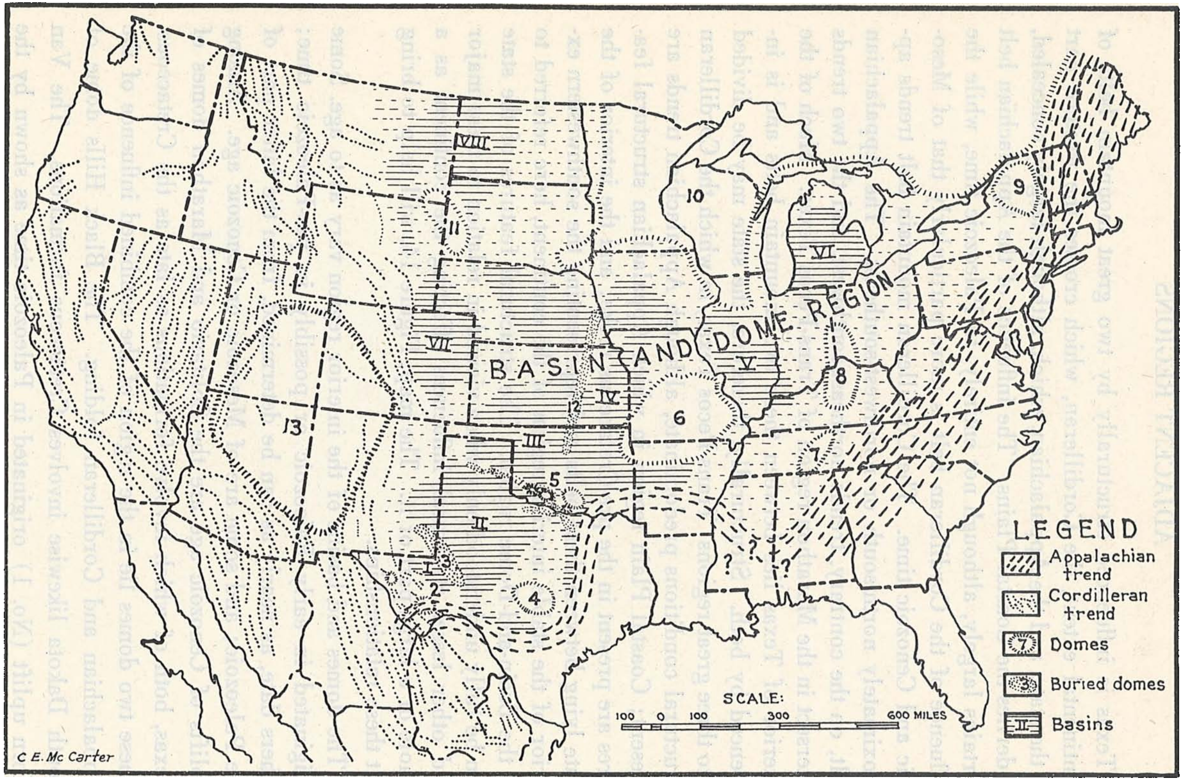


Fig. 14. Sketch map to show the relation of Texas structurally to adjacent regions.

STRUCTURAL RELATION OF TEXAS TO THE ADJACENT REGIONS

Texas is influenced structurally by two great mountain belts of continental extent, the Cordilleran, which crosses the western part of the state, and the Appalachian, which, although largely concealed, underlies the Coastal Plains. The influence of the Appalachian belt pertains largely, although not entirely, to Paleozoic time, while the influence of the Cordilleran belt is more particularly that of Mesozoic and Cenozoic time. The Cordilleran mountain belt trends approximately north-south or northwest-southeast. The Appalachian belt, on the contrary, trends northeast-southwest, and the two trends intersect in the Marathon region of Trans-Pecos Texas. Much of the interior of Texas lies between these two mountain belts and is influenced by both. Structurally, therefore, the state may be divided into three great regions: Trans-Pecos Texas, in which the Cordilleran structural conditions predominate, although Appalachian trends are present; Coastal Plain region in which Appalachian structural features are present in the pre-Cretaceous rocks; and the interior of the state lying between these belts and representing the southwestern exterior of the stable interior region of the continent, here referred to as the Basin-and-Dome region. The structural features of the state can be fully understood only when viewed in relation to these major and other lesser structural influences affecting the continent as a whole or a large part of it. The map, Figure 14, will help to bring out these relationships.

The domes and basins of the interior region vary as to age. Some originated in early Paleozoic or possibly in pre-Paleozoic time; others date, as nearly as can be determined, from the latter part of the Paleozoic; and some are of Mesozoic or Cenozoic age. Among uplifts of Cenozoic age are the Solitario and Marathon domes of Texas, both of which involve formations as late as the Cretaceous. These two domes lie in the region of the combined influence of the Appalachian and Cordilleran folding. The Black Hills dome of South Dakota likewise involves Cretaceous formations. The Van Horn uplift (No. 1) originated in Paleozoic time as shown by the overlap of Permian across the beveled edges of successively older formations towards the center of the uplift, and was subsequently, in relatively late geologic time, much broken by faulting. The age of the Llano, Red River, and Amarillo uplifts in Texas has previously been discussed. Among conspicuous domes and basins of this type in the interior region, originating in Paleozoic or earlier time, are the Ozark, Nashville, Cincinnati, and Adirondack domes (Nos. 6, 7, and 8 of fig. 11) and the Permian, Mid-Continent, Illinois, and Michigan basins (Nos. II, III, IV, V, and VI, of fig. 14).

STRUCTURAL MAP OF TEXAS

PLATE I (IN POCKET)

The geologic and structural conditions in Texas are so diverse that it is obviously impossible to map the entire state structurally on any one horizon or to express adequately the relationship to each other of the various horizons used. It has, therefore, been necessary in the accompanying structural map to treat various parts of the state separately and to map on the horizon best adapted to express structure in that particular area, or the one on which, from drilling records or otherwise, the most data are available. The most pronounced and widely recognized break in north-central Texas occurs at the top of the Ellenburger limestone. Accordingly, this horizon is selected for mapping structure in that region, notwithstanding that a great erosional unconformity occurs at this level. To the extent that differential erosion has occurred, mapping on this limestone fails correctly to express structure. However, with a few exceptions, such as excessive erosion on the Concho arch by which the entire Ellenburger limestone is in places removed, mapping on this limestone is believed to express the regional structural conditions with fair accuracy. In detailed mapping over small areas more satisfactory horizons may perhaps be found. The Woodbine formation in northeast Texas varies in thickness from a few feet to 700 or more feet. Obviously where the formation has been reduced in thickness by truncation, as at the east margin of the Northeast Texas embayment, mapping at the top of the formation fails to express fully structural conditions. Nevertheless for regional mapping this formation, which has been extensively drilled into, is the most satisfactory that has been developed in northeast Texas. In the structural map of the state, contouring, made originally on the top of the Woodbine, has been transferred to the top of the Georgetown formation.

In making this map on the Georgetown in northeast Texas, the writer has utilized structural maps on the Woodbine made by Plummer and Sargent and by Hudnall and Pirtle, supplemented by data from various sources. In transferring the contouring from the Woodbine to the Georgetown the writer has found very useful a thickness map of the Woodbine made by Hudnall and Pirtle. A map made in this way, including as it does estimates of thickness of several formations, will quite certainly fail in expressing the exact position of the Georgetown at many localities, and to that extent will fail to express accurately the structural conditions. Nevertheless, it has seemed best to continue the Georgetown (Main Street) as the mapping horizon entirely through northeast Texas, thus indicating structural conditions on a single horizon through a region of 650 or 700 miles in extent.* In the region of the Balcones fault zone and thence westward to Terrell County and eastward to the Louisiana border, the contouring is likewise on the top of the Georgetown formation. Coastward dip in this region carries the Georgetown formation below present drilling level. However, by projecting the dip gulfwards and by interpolating, after allowing for estimated increased thickness of formations, a belt about 40 miles in width adjacent to the Balcones zone is contoured at this level. In some parts of the coastal area this formation is provisionally contoured to a depth of –6500 feet. However, it is to be remembered that both projection of dip and estimates of thickness of formations involve difficulties in this region and the contouring of this formation in the Coastal Plain below –6000, sea level datum, is highly conjectural. Adjacent to the Llano uplift the Lower Cretaceous formations, as shown by this contouring, drop in level 7500 feet in 40 miles. If the dip continues at this rate, the Georgetown formation of the Gulf margin lies at a depth in excess of 25,000 feet. While such continued dip is possible, evidence as to the depth of the Georgetown formation under the Gulf margin, if there present, is not available at this time.

A large area in Trans-Pecos Texas is mapped on the base of the Fredericksburg division, the data being derived largely from surface exposures. For this mapping the author is indebted to Dr. Philip B.

*In east Texas adjacent to the Sabine uplift, the Georgetown is more or less reduced by erosion and locally in extreme northeast Texas may be absent, the Upper Cretaceous there resting on the Fredericksburg. Contouring on the eroded top of the Georgetown introduces an error which affects regional mapping slightly.

King of the United States Geological Survey. Mapping in the southern part of the Permian basin, contributed by E. F. Boehms of the Geological Division, The University of Texas Land Survey, is on the Yates sand which is near the top of the Whitehorse formation. In the southern High Plains the mapping, contributed chiefly by the California Company, is on the top of the Blaine. In the Amarillo region the mapping, adapted from Cotner and Crum,[139] is on the Permian "big lime" of that region which is of Wichita age. Some data derived from work carried on under a grant from the Penrose Fund of the Geological Society of America (No. 44–33) have been used in making the map.

Of the Cenozoic formations it was found desirable to use the Carrizo in the Rio Grande embayment, the Weches in northeast Texas, and the *Textularia hockleyensis* and *Heterostegina* zones in the region near the Gulf Coast. For three of the counties bordering the Gulf, Cameron, Kenedy, and Willacy, no data on these horizons are available.

In certain regions of the state it has not been practicable either from lack of sufficient data or on account of the complicated structural conditions to represent structure by contouring. Such regions are the pre-Cambrian area of the Llano uplift and the Paleozoic areas of the Marathon and Solitario uplifts. In these areas structural conditions are represented not by contouring but by graphic representation chiefly by trend lines. This representation of structural conditions for the pre-Cambrian area of the Llano uplift has been contributed by H. B. Stenzel and for the pre-Permian area of the Marathon basin by Philip B. King.

In making the structural map the writer has been guided as follows:

1. For any region the structural conditions are shown at one horizon only. In only a few places are contours of one horizon superimposed on those of another horizon.
2. The contour horizon selected for each region of the state is the oldest or stratigraphically lowest horizon on which sufficient data are available to map in a satisfactory way. The oldest available horizon is selected because it records, with local possible exceptions, the maximum structural deformation that can be determined for that particular region.
3. As little interpolation as possible is used in determining horizons. Some fixing of contours by interpolation is obviously necessary.

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[139]Cotner, Victor, and Crum, H. E., Geology and occurrence of natural gas in Amarillo district, Texas: Bull. Amer. Assoc. Petr. Geol., vol. 17, pp. 877–906, 1933.

4. When necessary to map on erosion surfaces, in so far as is practicable allowance is made for erosion.
5. As few horizons as possible, consistent with the conditions named, are used in mapping.

ACKNOWLEDGMENTS

The principal oil and gas fields and the salt domes of the state are shown on the map. In locating the oil fields the writer has made use of the published literature, particularly a map issued in 1931 by the United States Geological Survey.[140] For aid in locating fields discovered since 1931 the writer is indebted to several of the oil-producing companies and to many geologists in the state. In so far as practicable, the names of the oil fields have been written in on the map. In some parts of the state, however, the oil and gas fields have become so numerous that it is impossible to enter the names of all of the fields on a map of this scale. In determining appropriate names for the many oil fields much assistance has been given by the several geological societies of the state. Another source of names for these fields is the volume on Petroleum Development and Technology, issued annually by the American Institute of Mining and Metallurgical Engineers. The latest volume of this series available is that for the year 1935.[141]

Oil and gas producing companies of the state that have contributed data for the structural map, or for the location of oil fields and salt domes, or both, include the following: Amerada Petroleum Corporation, Atlantic Oil Producing Company, California Company, Kirby Petroleum Company, Gulf Company, Humble Oil and Refining Company, Lone Star Gas Company, Magnolia Petroleum Company, Pure Oil Company, Shell Petroleum Corporation, Sun Oil Company, Texas Company, Tide Water Oil Company, United Gas Company, and others. Particular acknowledgment is made to the following geologists of these and other companies: John E. Adams, W. S. Adkins, M. B. Arick, F. W. Bartlett, Olin G. Bell, M. H. Billings, E. F. Boehms, W. F. Bowman, V. A. Brill, H. P. Bybee, L. D. Cartwright, Jr., M. G. Cheney, Herschel H. Cooper, C. D. Cordry, T. C. Craig, Alexander Deussen, Adolph Dovre, J. Brian Eby, H. B. Fuqua, A. E. Getzendaner, F. M. Getzendaner, J. M. Hancock, W. T. Hancock, Jr., H. A. Hemphill, J. S. Hudnall, M. C. Israelsky, John S. Ivy, Wayne V. Jones, Archie R. Kautz, John A. Kay, P. B. King, Hedwig T. Kniker, A. I. Levorsen, R. A. Liddle, J. T. Lonsdale, J. B. Lovejoy, H. J. McLellan, Lewis W. MacNaughton, Vaughan Maley, Willis A. Maley, J. J. Maucini, C. A. Mix, J. I. Moore, P. D. Moore, G. D. Morgan, H. J. Morgan, E. Obering, Leonard W. Orynski, Frith C. Owens, Virgil Pettigrew, T. F. Petty, G. W. Pirtle, E. L. Porch, R. S. Powell, W. Armstrong Price, Wallace Ralston, Gene Ross, Robert Roth, P. G. Russell, George Sawtelle, I. R. Sheldon, H. C. Spoor, Jr., B. E. Thompson, S. A. Thompson, Wallace C. Thompson, A. K. Tyson, Felix A. Vogel, E. A. Wendlandt. Many others have contributed directly or indirectly. Particular acknowledgment is made to C. E. McCarter who has not only acted as draftsman but has also given material assistance in assembling data for the map. Those who have contributed data are in no sense responsible for any errors that may exist in the completed map.

The base map of Texas on the scale 1:1,000.000, on which the structural contours are printed, has been obtained by photographic reduction from the base map on scale 1:500,000 issued by the United States Geological Survey.

The generous coöperation of the oil companies operating in Texas, of Texas geologists, and of the Federal Survey is very greatly appreciated. Without such coöperation this map could not have been made.

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[140]Oil and gas fields of the state of Texas: prepared by G. B. Richardson, 1931.

[141]See Chapter IV, Production. Frank A. Herald, Vice-chairman. Papers on the Texas region by several authors

Part 2

MAJOR STRUCTURAL FEATURES OF TRANS-PECOS TEXAS

CHARLES LAURENCE BAKER

INTRODUCTION

TRANS-PECOS REGION

The part of Texas which is truly mountainous is situated west of Pecos River. To this territory the regional term Trans-Pecos is generally applied. The Trans-Pecos region is properly that which lies between Pecos River and the Rio Grande and includes a large territory in New Mexico as well as in Texas. The region is not all mountainous, since plains extend from Pecos River to the foothills of the mountains, and farther west, lowlands lie between mountain ranges. Some of the Trans-Pecos mountains are really plateaus, deeply dissected by erosion in some of their marginal areas; others are asymmetrical ranges, or cuestas, with a steep scarp on one side and gentler slope on the other, others are more or less isolated rugged peaks or ridges, some places grouped together more or less irregularly and some places found in linear belts. The Trans-Pecos mountains form a section of the great North American Cordillera which extends into New Mexico and continues across the Rio Grande into Mexico.

INTERMONTANE LOWLANDS[1]

The later Cenozoic mountain-making movements in Trans-Pecos Texas appear to have changed the face of the landscape almost entirely, creating mountain uplifts separated by lower basins. Since then the Rio Grande and its tributaries have drained the basins along their courses. Very possibly the Rio Grande has been through-flowing since the uplifts, because it rises in high mountain ranges with large rain- and snowfall. Most of its tributaries in their middle and lower courses have, on the other hand, extended their courses upstream, thereby draining intermontane basins. One of the more

[1]Among publications relating to intermontane lowlands in Trans-Pecos Texas cited in the bibliography of Vol. I are the following: Baker, 46; Richardson, 1304, 1312, and 1314.

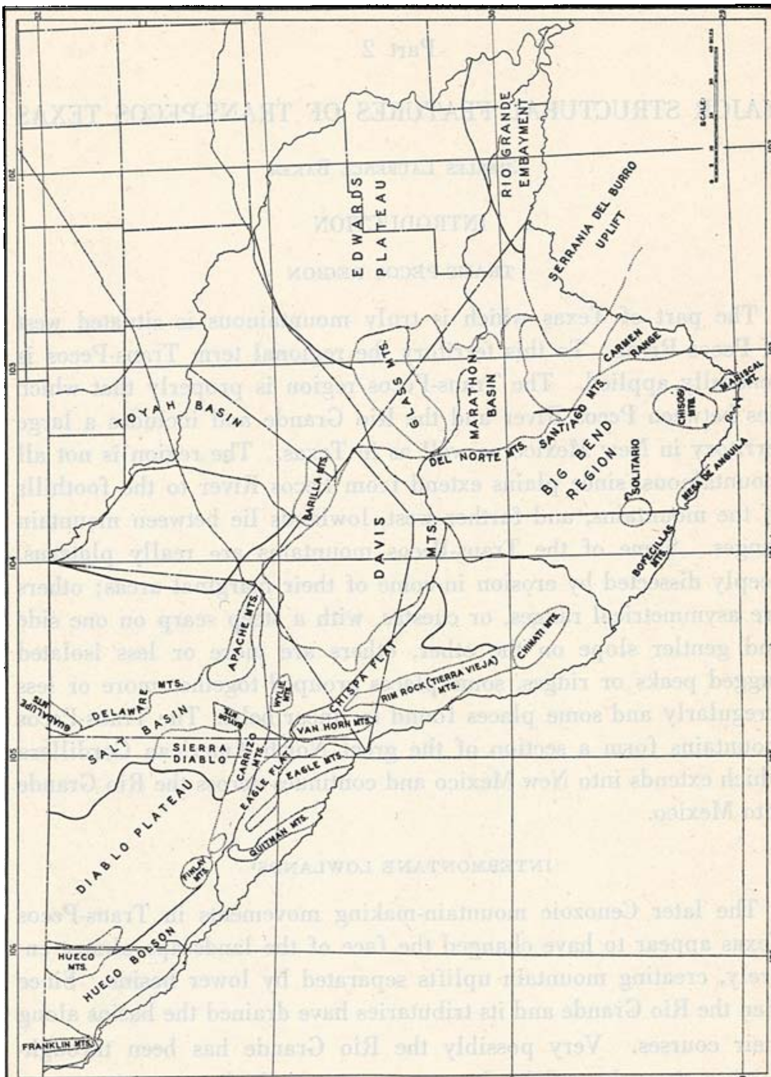

Fig. 15. Sketch map to show the principal subdivisions in Trans-Pecos Texas.

extensive intermontane basins still exists in Trans-Pecos Texas. It is the Salt basin, the drainage area of which extends from within a few miles north of the Rio Grande north of the Chinati Mountains, northwards into southern New Mexico. A probable underground bed rock barrier a short distance north of Lobo* station separates this basin into two parts, a southern, which is mainly synclinal, and a northern, the borders of which are marked in part by upfaulted scarps. There still exists another small basin, the Eagle Flat basin near Eagle Flat station on the Texas and Pacific Railway. This was formerly more extensive, but its eastern part has been captured by drainage now reaching Salt basin. Formerly the entire course of the Rio Grande as far downstream as the Boquillas canyons in the lower part of the Big Bend was also a basin. The Hueco Bolson, now drained by the Rio Grande, is a part of a much more extensive interior basin which extends to central New Mexico, the northern part of which is the still undrained Tularosa basin.

The basin areas are very deeply filled with deposits from the erosion of the surrounding mountains. In the Chispa Creek valley, which is the southern part of the Salt basin, the basin deposits are 872 feet thick under the town of Valentine. A well at Hot Wells in the Eagle Flat basin was still in basin deposits at 1000 feet. A well at Torbert, 1165 feet deep, did not reach their base, and another well at the head of Green River (Glenn Creek) did not entirely penetrate them at 1100 feet. Other measurements as to depth of fill in these valleys are given on pages 171 and 204.

The finer-textured deposits in the middle of the basin of the Rio Grande are exposed from east of Finlay to west of El Paso and south of the Malone and Quitman mountains. From these mountains to the head of the Boquillas canyons they are found mainly on the Mexican side of the river. They extend, likewise, into Mexico a long distance south of El Paso. They outcrop also in Texas west of the Chinati Mountains between Ruidosa and Presidio. These lacustrine deposits are finely textured and laminated, and since they contain much disseminated gypsum, the water in which they were laid down contained considerable mineral matter. Towards the mountains, the lake silts grade into conglomerates, some of the best sections of the latter being found along lower Pinto Canyon west of the north end of the Chinati Mountains. After the draining of the lake or lakes, the lacustrine deposits were covered by a sheet of gravel swept down from the mountains. In the vicinity of El Paso this gravel contains Pleistocene vertebrates. During the lowering of

*Lobo is a station on the Southern Pacific Railroad about midway between Chispa and Van Horn.

the stream beds of the Rio Grande and its tributaries, the lake beds were greatly dissected. The downcutting of the river beneath the gravel sheet capping the "mesa" in the vicinity of El Paso amounts to 350 feet and took place during the later part of Pleistocene time. This dissection is well shown on the Canutillo, Texas-New Mexico topographical map of the United States Geological Survey.

The Rio Grande probably originally existed as a stream flowing into the lake or lakes. It subsequently has drained the basins, either by reaching back into them, or by the lakes' overflowing and cutting down their own outlets. Or the outlets from the basins may have been originally subterranean channels in their limestone rims, the roofs of which have subsequently collapsed.

Each basin formed a local base-level during the time of its existence. The base-levels are well exhibited as the surfaces of the erosion-cut or "pediment" surfaces of the bed rocks in numerous places, such as in the flanking mountain slopes west of the Rim Rock, in the basin of upper Cibolo Creek on the east flank of the Chinati Mountains, in the lower Big Bend, and in Green Valley, and the Marathon basin. Much at least of the Marathon basin was eroded out of the Marathon dome during the basin epoch, and in Green Valley a thick succession of volcanic rocks was stripped from an area 25 miles in maximum breadth. Rejuvenation along tributaries of the Rio Grande has now reached so far back that it has dissected most of the old rock pediment and its gravel capping. This dissection is a process very active at present. Fifty years ago the upper course of the present Terlingua Creek was scarcely defined in Green Valley, where today there is a well-defined channel. The recent erosion is probably aided by the destruction of the former grass cover through overstocking the range. During an exceptionally rainy period in the winter of 1890 a steep-walled arroyo course was cut down a trail leading from the upper drainage basin of Calamity Creek to the head of Terlingua Creek, and since then most of the drainage from upper Calamity Creek has been diverted into Terlingua Creek.

SOME MAJOR DIFFERENCES IN STRUCTURAL RELIEF

Some conservative estimates are given below of uplift and depression in (1) the northern or more plateau-like province of Trans-Pecos Texas, (2) the border zone between this province and the one to the south, (3) the Van Horn uplift, (4) the Davis Mountains. (5) the easternmost ranges, and (6) the Big Bend sunken block.

(1) The bed rock floor of the Hueco Bolson at the New Mexico line probably lies at least 6000 feet lower than the summits of the Hueco Mountains and 8000 feet lower than the highest part of the Franklin Mountains.

(2) The city of El Paso lies in a depressed area dropped below the south end of the Franklin Range probably at least 2000 feet and perhaps considerably more. Farther east where the Mexican overthrust province joins the synclinal area of the south-central Diablo Plateau, between Finlay and Eagle Flat, the Cretaceous rocks of the overthrust area, although dipping steeply southwest, reach as great elevations as in the Diablo Plateau. Directly to the east, however, the southward dip of the Cretaceous off the summit of the Van Horn uplift is at least 7250 feet in a distance of 45 miles. Farther east the southward dip in the Apache and northern Davis Mountains is more than 2000 feet.

(3) The structure in the summit of the Van Horn uplift in the southern Carrizo Mountains is at least 7250 feet higher than in the San Carlos dome 45 miles to the south and at least 10,250 feet higher than in the downdropped block just west of the San Carlos dome. If 1000 feet of Ordovician limestone once covered the Carrizo schist of the Carrizo Mountains, these figures must be increased by that amount. On the north flank the base of the Permian lowers 2000 feet northwards from the southeast corner of the Diablo Plateau within a distance of 10 miles.

(4) The Davis Mountains occupy a structural depression between the Marathon dome and the Apache-Delaware mountain uplift. The base of the Cretaceous lowers probably 3000 to 3500 feet from Star Mountain at the northeast base of the Davis Mountains west-southwest to the San Carlos dome of the Rim Rock country, but most, if not all, of this sinking may have occurred during Cretaceous deposition, since the Cretaceous thickens perhaps 3000 to 3500 feet west-southwestwards to the Rim Rock. The base of the Cretaceous lowers about 2200 feet southeast from the Apache Mountains to the Star Mountain anticline, and thence, continuing in a southeast direction, rises about 4000 feet to its highest elevation in the Glass Mountains. However, the Permian horizons probably reach about as high in the

Apache as in the Glass Mountains; hence, the maximum amount of structural downwarping in the northeastern Davis Mountains is probably approximately 5000 feet, since the figures given above are for an anticlinal uplift within the Davis Mountains. The physiography suggests that the valley extending northeastwards from Paisano Pass lies in a synclinal depression between the Marathon dome and the Davis Mountains.

(5) The structure along the easternmost ranges, assuming the base of the Fredericksburg Cretaceous to have been originally horizontal, lowers about 5000 feet from the Guadalupe Mountains at the New Mexico line in a southeastward direction to the Rio Grande canyon across the Sierra del Carmen, although the surface of the Wichita paleoplain of Hill slopes in the same direction 7000 feet or more.

(6) The east edge of the downdropped block of Burro Mesa, which is structurally the lowest part of the Big Bend sunken block, is about 7000 feet lower structurally than the summit of the Carmen Range and 5000 feet lower than the Mesa de Anguila, which is the upthrown side of the great Terlingua fault. The base of the Cretaceous in the Burro Mesa graben is perhaps 5000 feet beneath sea level. The surface of the Wichita paleoplain, developed previous to the advance of the Cretaceous sea, has suffered deformation until, at the present time, it has a relief in Trans-Pecos Texas from a maximum of about 10,000 feet above sea level, or perhaps a little more where extended over the summit of El Capitan Peak in the Guadalupe Mountains, to perhaps 5000 feet below sea level in Burro Mesa.

(7) The southeastward dip of the Permian from El Capitan Peak in the Guadalupe Mountains to the trough of the Toyah basin syncline where it crosses Pecos River halfway between Barstow and Grand Falls amounts to 10,500 or perhaps 11,000 feet in a distance of 110 miles or 100 feet per mile.

The base of the Cretaceous in Maverick County, Texas, 340 miles southeast of the Guadalupe Mountains, is approximately 8000 feet below sea level, and along the Gulf Coast, 550 miles southeast of the Guadalupe Mountains, is probably at least 15,000 feet beneath sea level, and at the mouth of the Rio Grande it may be 20,000 feet beneath sea level. The base of the Cretaceous, therefore, has an average dip gulfwards of approximately 50 feet per mile.

MOUNTAIN-MAKING EPOCHS AFFECTING TRANS-PECOS TEXAS

The mountain region of Trans-Pecos Texas has been subjected to mountain-making forces since very early geologic time. These forces have not operated continuously. There were four or more distinct epochs of activity of long duration, each separated from the succeeding by an extended period of time. During the quiescent periods, the mountains were greatly denuded by erosive processes. The mountains as they are at present were made almost entirely by the latest of these movements, which built upon the ruins of at least three older mountain systems. The former systems were not entirely co-extensive with the present systems.

The structures produced by the earlier movements are now visible only where the older rocks subjected to them have been bared by erosion subsequent to the latest mountain-making epoch. Such are the areas where the greatest amount of uplift has occurred. Certain effects of the older deformations may be detected as influencing the later, some of the older structures apparently having been renewed to a certain extent long after their original formation.

PRE-ORDOVICIAN DEFORMATIONS

The Carrizo Mountains and certain areas in the Wylie, Van Horn, and Eagle mountains, centering not far from the junction of the 31st Parallel and 104th Meridian, will be called in this account the Van Horn uplift, from Van Horn, county seat of Culberson County. The uplift exposes the old metamorphic and intrusive rocks of the basement complex where they are elevated highest in the state of Texas.

The Lower Ordovician El Paso limestone of Beekmantown age is the oldest formation in this uplift the age of which is known from fossils. The El Paso overlies with angular unconformity the Van Horn formation, which is made up mostly of arkosic sandstones and conglomerates and has usually been considered as of Upper Cambrian age. Inasmuch, however, as it differs from other known Upper Cambrian formations of Texas in not containing glauconite and marine fossils, the Van Horn may be possibly pre-Cambrian or Cambrian older than the other Texas Upper Cambrian strata. This possibility is strengthened by the angular unconformity between it and the Lower Ordovician, which is not known to occur between Upper Cambrian and Lower Ordovician in the other sections. It is for these reasons that the oldest known deformations in the Trans-Pecos area are herein referred to as pre-Ordovician.

The Van Horn sandstone rests with profound angular unconformity upon two older complex series of rocks. The younger of the two is the Millican formation of red sandstones, conglomerates, and marbles. The red sandstone of the Millican is practically unmetamorphosed and is dominantly fine grained. The associated cherty limestone and conglomerate, although in places minutely crumpled and with stretched pebbles in the conglomerate, are metamorphosed only locally even where the original limestone has been changed to true marble. The Millican was considerably folded and eroded before the Van Horn formation was deposited upon it. The dominant trend lines of the Millican deformation, so far as determined, appear to be northwest-southeast to east-west. Diabase dikes intrude the strata.

The other rock group, the Carrizo Mountain, is completely metamorphosed, consisting dominantly of schists, with some slates, quartzite, and gneiss. These rocks are cut by pegmatite, graphic granite, quartz, aplite, and basic igneous dikes. The intense metamorphism of the Carrizo Mountain indicates that it is probably older than the Millican, and the latter contains pebbles of schist similar to the schist of the Carrizo Mountain. The structural trends of the Carrizo Mountain, although variable, are prevailingly northeast-southwest, or more or less at right angles to those of the Millican.

The metamorphic rocks of the Carrizo Mountain and those of ancient date elsewhere in the Trans-Pecos province of Texas and New Mexico show relatively little minute and complicated crumpling. At the foot of the western scarp of the Wylie Mountains the strata lie in broad bands dipping southward at gentle angles. In the type locality of the southern Carrizo Mountains similar broad, mainly even, bands dip uniformly southeast. The dip is steep to the southeast in the northeastern front scarp of Eagle Mountains. In the northern Van Horn Mountains, at the Mica Mine locality, where there is later local doming, the dip is mainly east, changing farther south to south-southeast and, at the extreme south, to east. East of this locality and two miles west of Lobo railroad station the dip is south. Therefore, in the visible exposures the dip is mainly southeast but is south on the extreme east. The structure as a whole is either extremely recumbent isoclinal or else the rocks were metamorphosed by pressure more nearly vertically directed; detailed areal mapping is necessary to determine which is the fact.

The Millican is separated from the Carrizo Mountain by a zone of faulting which probably was already existent before the Van Horn formation was laid down and on which renewed movement occurred during later mountain-making periods. Northwest of Eagle Flat railroad station, according to King, the Carrizo Mountain is thrust northward over the Millican.

The structures described above were existent before the Van Horn sandstone was deposited. The dominant strike of the Millican is parallel with that of the basement complex schists and gneisses of the Llano uplift and of the far later Cordilleran orogeny. The most prevalent strike of the Carrizo Mountain is in the same direction as the axial lines of the late Paleozoic or Variscan orogeny of the Marathon and Solitario areas. Some geologists think that later foldings and faulting have followed axial lines which were originally made in the oldest rocks, or that the original "grain" (the strike or trend of banding in very ancient metamorphic rocks) has determined the lines along which later deformations have occurred. One familiar with both areas will be impressed with the resemblances between the Vishnu schist of the Grand Canyon section, Arizona, and the Carrizo Mountain schist of the Texas section, and between the Grand Canyon series and the Millican series.

There appear to be three pre-Ordovician mountain-making epochs in the Van Horn uplift. The first was a time of metamorphism of the Carrizo Mountain formation. After a time of prolonged erosion and the deposition of the Millican the latter was folded. Erosion followed and then the Van Horn formation was deposited. Later the Van Horn formation was tilted and eroded before the deposition of the Lower Ordovician sediments. Of these, the post-Van Horn movement was apparently considerably less intense than the two earlier.

MARATHON, OR VARISCAN,[2] DEFORMATION OF LATE PALEOZOIC TIME

The Marathon or late Paleozoic orogeny extends into the territory of the later Cordilleran mountain system in Brewster County, and

[2]In Europe the mountain system formed by approximately contemporaneous movements of late Paleozoic time is known as the Variscan. This mountain system once extended over a large territory in Europe and Asia as well as in southeastern America. The Eurasian system is also called the Hercynian, a term essentially synonymous with Variscan.

evidences of late Paleozoic movements are found elsewhere in the Trans-Pecos mountains wherever the older Paleozoic rocks are brought to the present surface through the combined processes of uplift and erosion.

The folded Paleozoic formations become exposed to the view through post-Cretaceous uplift just east of the boundary between Pecos and Brewster counties (Vol. I, p. 127). West of the Marathon basin exposures, the Paleozoic rocks are again buried beneath Cretaceous and Cenozoic but reappear for the last time in Texas in the heart of the domical uplift of the Solitario on the Brewster-Presidio county line about 12 miles north of the Rio Grande.

The most intense mountain folding and faulting known in these formations are in mainly detrital or clastic sediments which occupied originally a great trough or depositional geosyncline, situated north or northwest of a land area of mainly metamorphic and igneous rocks. Biotite schists are visible in a small exposure about 6 miles south of where the Rio Grande cuts the Boquillas canyon through the Sierra del Carmen on the border between Brewster County, Texas, and Mexico. These may be either pre-Cambrian or strongly metamorphosed rocks of the Marathon orogeny.

The structural geologist wishes that the border area between the old land masses which furnished the deposits and the trough receiving the deposits were now visible, since it is suspected that the structure in this belt would be even more complicated, and the rocks more metamorphosed, than in the part of the folded area now visible.

North and northwest of the intensely folded and faulted area occupying the original trough of maximum deposition (the geosyncline), the deposits are less thick and were laid down in clearer water. Hence, they are particularly characterized by a greater percentage of limestone and are known as the "foreland" facies, in distinction to the more detrital geosynclinal facies. This foreland facies flanks towards the interior of the continent the Marathon belt, and exposures of it occur in the Van Horn uplift, the eastern escarpment of the Sierra Diablo, and the Hueco and Franklin mountains of Trans-Pecos Texas.

The mountain folding most likely began in early Pennsylvanian or in late Mississippian time, reached its greatest intensity before the beginning of the Permian, experienced some feeble renewals during the Permian, and ended perhaps after the deposition of the Upper Triassic sediments of the Staked Plains. The mountain folds were bevelled and their sites reduced to a plain before the advance of the Cretaceous sea.

The axial or strike line of the folding is east-northeast in most of the area, but at the eastern margin of the Marathon basin is east-west. In the Solitario the original axes have had their strike changed in part by the later doming.

The most intense folding now visible is in the Marathon and Solitario areas, in both of which the limits of the more intense deformation are invisible because covered by the Cretaceous rock. In both areas the rocks were closely folded and some of the folds overturned to the northwest, giving some of the strata isoclinal structure. Some of the folds fractured on their northwestern flanks, and overthrust sheets were forced still farther northwest. Some of the thrust planes which originally dipped to the southeast were themselves folded during a later phase of the movements. Subsequent erosion has exposed, at the southeastern margin of the Solitario, one of the folded overthrusts in the center of which outcrops the Carboniferous Tesnus formation overlain on all sides by the older Ordovician rocks, which dip away from the Carboniferous center. Such an exposure of younger rocks surrounded by really older but overlying rocks in a folded overthrust is known as a "window" (German "fenster").[3]

The exposures of closely folded rocks are separated by a considerable distance from the other outcrops of Pennsylvanian and earlier strata of Trans-Pecos Texas, which are situated farther northwest. In the Van Horn uplift, Diablo Plateau, and Hueco Mountains, these strata are only gently and broadly folded, the rocks as high as the Pennsylvanian having greater dips in some localities than those of the Permian. Difference in dip between Pennsylvanian and Permian is appreciable in the eastern Diablo Plateau at the bend in the escarpment north of the Figure 2 ranch, and in the Hueco Mountains. In the Van Horn uplift the Permian overlaps the older formations and rests in places on the pre-Ordovician. In Trans-Pecos New Mexico there is often greater dip in the Magdalena than in the unconformably overlying Abo formation, the lower strata of the Abo

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[3]A geologic map of the Solitario uplift is given in Vol. I, p. 119.

appearing in at least some places to be Pennsylvanian of a stage considerably higher than the Magdalena. Although the earlier Pennsylvanian is known to be separated from the later by an epoch of deformation in the Llano uplift, in the Bend arch, in the Amarillo "high," in the Red River arch, and in southern Oklahoma, late Pennsylvanian folding is not known in north-central Texas. Here the strata were gently and broadly folded, after the Upper Triassic was deposited, into the great geosyncline of the Llano Estacado.

LARAMIDE DEFORMATION OF LATE CRETACEOUS TIME

Mountain-making movements occupying the time interval between the beginning of the Benton or Eagle Ford epoch at the base of the Upper Cretaceous and the Wasatch stage of the mid-Eocene are known as Laramide.

After the disturbance of the Variscan mountain-making had ceased, a long period of erosion ensued. During this time the mountains were worn down to low rolling hills or plains, and the Wichita paleoplain of Hill was extensively developed over perhaps all of Texas and at least part of adjacent Mexico. Over the low-lying land the sea again began to advance. Beginning in southern Mexico, in the Lower Jurassic, it subsequently spread northward, reaching the site of the Malone Mountains, just north of the Rio Grande and west of Sierra Blanca, in the Upper Jurassic. Then, during the various stages of the Lower and Middle Cretaceous, it spread over the remainder of Trans-Pecos Texas, and in Upper Cretaceous time extended northwards to the Arctic Ocean. Marine sedimentation continued through Middle and most of Upper Cretaceous time. During the marine sedimentation, a much deeper depositional geosyncline existed, near the Mexican border, which is here named the Mexican geosyncline, since its deepest part lay in the eastern section of that country. Sediments reaching a thickness of as much as two miles were laid down in the territory through which the Rio Grande now flows, the strata thinning towards the north and northeast, and some of them, particularly those of the base and top of the section, not being present at all in that direction.

Sometime after the deposition of the Taylor (Pierre) marine sediments of the Upper Cretaceous, the sediments in southern Trans-Pecos Texas were deformed into broad and gentle folds. In that part of the Trans-Pecos north of the Texas and Pacific Railway only Lower and Middle Cretaceous strata are now exposed. They are less folded than the Cretaceous rocks farther south, and the deformation they and the underlying Permian have experienced is considered here more apt to be for the most part later Cenozoic than Laramide, although this view is not susceptible to definite proof.

In southern Trans-Pecos Texas, and more particularly in the marginal areas of a broad central area of lesser relative uplift, which extends from the north and east flanks of the Davis Mountains to beyond the Big Bend of the Rio Grande, there is angular unconformity between Cretaceous and earlier rocks below and the volcanic series. Few diagnostic fossils have been found in the volcanic series, but those now known are of the earlier Tertiary. The differences in dips between the Cretaceous rocks and the volcanics are not very great, indicating that the Laramide deformation was not very intense. In the heart of the Big Bend region, in the area surrounding the Chisos Mountains, and in the Rim Rock country of northwestern Presidio County the highest Cretaceous marine strata, so far as we know definitely, are of Taylor age, although there is yet a possibility that marine lower Navarro occurs. These localities contain the highest marine Cretaceous in the Trans-Pecos province. East of Pecos River there are higher marine Cretaceous beds. In the southern Big Bend and the Rim Rock localities the marine Cretaceous grades upwards into plant and dinosaur beds, which contain a great deal of sand and some volcanic ash. These fresh water strata are overlain without any intervening known stratigraphic break by the Tornillo formation, also dinosaur-bearing and having a large amount of volcanic tuff but containing little sandstone and some relatively rare conglomerates. In the Chisos Mountains area the Tornillo may grade up without marked stratigraphic break into the Chisos tuffs, and the break which should indicate the Laramide orogeny is not known and apparently is not present, although a few thin conglomerates in the middle and upper Chisos formation indicate erosion of neighboring land. The Crown conglomerates at the top of the Chisos formation are thicker and coarser and contain boulders of Carboniferous and Lower Cretaceous limestones. Altogether, the total amount of non-volcanic detritus in a section at least 2000 feet thick of the Chisos formation is not over 5 per cent.

In the vicinity of the old coal mines at San Carlos, in the Rim Rock country, the Laramide orogeny is shown by an unconformity between the Tornillo and Chisos. The measured section shows 1020 feet of Tornillo sediments overlying the highest coal horizon. This section is topped by an unconformity and a heavy basal conglomerate containing many boulders of Lower Cretaceous limestones and boulders up to several feet in size of Cox sandstone of Trinity age. The conglomerate is overlain by a section 1500 feet thick of mainly tuff, which resembles the Chisos beds.

Proceeding northward in the Rim Rock country from San Carlos the basal conglomerate of the volcanic series is found to rest upon successively older beds until at the north end it rests on the Eagle Ford. Going southward from San Carlos, it is found to rest likewise on successively older strata as far as Pinto Canyon, where it rests upon Permian of Word age. The tuffs referred to the Chisos formation thin both to the north and south of San Carlos and the succeeding lava flows overlap the older rocks. The San Carlos area, therefore, was the site of a Laramide syncline in which a thick section of Upper Cretaceous rocks was preserved and covered by a thick series of tuffs. To the north and south, older rocks of the synclinal flanks were being eroded but later became covered as volcanic activity continued.

The beginning of the Laramide epoch of orogeny is indicated by the deposition of sandstones in later Taylor time. After the deposition of the succeeding plant- and dinosaur-bearing sandstones and clays, volcanic activity had increased to so great an extent that pure sandstones became very rare, although some sand detritus was deposited along with the tuffaceous clays of the Tornillo. The climax of the Laramide orogeny in the Trans-Pecos province came at the end of Tornillo time, as shown in the San Carlos area, where the youngest known beds beneath the unconformity are found. In the Chisos Mountains, another synclinal area, deposition may have been continuous between the Tornillo and the Chisos since no known unconformity indicates the time of the orogenic climax.

The post-Cretaceous thrusts, referred by others and formerly by the writer to Laramide times, are now considered by the writer as possibly at least in part of later date.

LATE CENOZOIC OR CORDILLERAN DEFORMATION

The volcanic series, which has been shown to be later than the Laramide orogeny, is at present very unsatisfactorily dated by fossil evidence. The series contains abundant tuffs, lake deposits, and some conglomerates which probably will afford a considerable amount of fossil evidence to collectors of adequate experience, but the search for fossils is still to be undertaken. There is a little evidence of the age of some of the lower volcanics but none of the upper parts of the series. Even in the lower rocks fossil evidence is confined to two localities, one a small area in the Barilla Mountains of the Jeff Davis-Reeves county border and the other only a few miles distant in the northeastern Davis Mountains. Fossil leaves were found in the basal rhyolitic tuffs which unconformably overlie the Taylor Upper Cretaceous in the Barilla Mountains. Professor E. W. Berry[4] considered that these plants were more likely of Wilcox Eocene age. A tooth of *Hyracodon*,[5] a rhinoceros of Lower or Middle Oligocene age, was found in the tuffs within 200 feet of the base of the volcanic series on the Casey ranch, northeastern Davis Mountains. It is suggested that these fossiliferous tuffs, possibly but not certainly contemporaneous with the Chisos tuffs of the southern Big Bend, which may be older, are of the age of the dominantly tuffaceous Frio and Catahoula formations of the Gulf Coastal Plain. However, the basal volcanics may prove to vary in age in different localities.

The volcanic series is deformed by broad gentle folds in the Davis and Barilla mountains and faulted in the southern Big Bend, where the maximum fault displacement is about 2000 feet on the east side of Burro Mesa, and in the Rim Rock country and Chinati Mountains of western Presidio County, where the maximum known fault displacement is about 3000 feet in the San Carlos area.

Evidence for the dating of the latest folding and faulting productive of the present mountains and basins at present is not known in Trans-Pecos Texas. Age determinative fossils will probably be found in the Rio Grande lacustrine and alluvial basin deposits, but very little search has been made for them. Consequently we must

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[4]Berry, E. W., An Eocene flora from Trans-Pecos Texas: U. S. Geol. Surv., Prof. Paper 125, pp. 1–9, 1919.

[5]The locality from which this specimen came was discovered by R. L. and Joe Cannon and J. B. Carsey; the determination of the tooth was made by R. A. Stirton.

go to Mexico, New Mexico, and the High Plains and Gulf Coastal Plain of Texas in order to procure the necessary data.

Marine Miocene strata are folded with the earlier Tertiary and Cretaceous rocks on the east side of the Sierra de Tamaulipas in northeastern Mexico. The best section is exposed along the Rio Soto la Marina between where the river crosses the axis of the Sierra de Tamaulipas and where it enters the Gulf. In the state of Hidalgo, Mexico, E. D. Cope[6] found a coal-bearing series with "Loup Fork" vertebrate fossils overlying with angular unconformity the folded and eroded Cretaceous.

Cope also found that the Santa Fe formation of the Rio Grande basin in northern New Mexico contained a "Loup Fork" vertebrate fauna. In recent years further collections and studies have been made by other vertebrate paleontologists, and at the present time the Santa Fe formation is placed at or very near the border between the Miocene and Pliocene. The Santa Fe formation was deposited in an intermontane basin formed by orogenic movements, and its deposits have unconformable relationship with the older rocks.

The northern High Plains of northwest Texas are capped by water-transported sands and gravels and higher eolian deposits in which has been found a fairly large mammalian fossil assemblage of lower Pliocene age. These deposits overlie a peneplain formed on a surface of Triassic, Permian, and Comanche Cretaceous rocks, and they extend farther westward and northwestward into the area lying at the eastern foot of the Cordillera. On the Sierra Grande uplift and in the Raton basin they lie with angular unconformity upon Upper Cretaceous and presumably older Eocene strata. The lower Pliocene, which is the oldest Tertiary of the High Plains, was deposited consequential to the Cordilleran orogeny.

More recently, Alexander Deussen has found in the lower conglomerate member of the Goliad formation on Medio Creek, Bee County, Texas, in the Gulf Coastal Plain, the jaw of a large rhinoceros identified at *Teleoceras* cf. *T. fossiger* (Cope) and teeth of the horse *Hipparion ingenum* (Leidy). There is very little possibility that these fossils can be younger than middle Pliocene, and they

[6]Cope, E. D., The Loup Fork Miocene in Mexico: Amer. Nat., vol. 19, pp. 494 495, 1885; and Report on the coal deposits near Zacualtipan in the state of Hidalgo, Mexico [and description of mammalian fossils from Tehiuchila, Vera Cruz]: Proc. Amer. Phil. Soc., vol. 23, pp. 146-151, 1886.

can be lower Pliocene. The sediments which contain them may not be the oldest gravels of the Goliad formation, which formation certainly overlaps older strata and consequently may contain strata varying in age in various localities.

The dating of the beginning of Cordilleran orogeny, late Miocene or early Pliocene, is fairly satisfactory, but the time when the deformation ended is still unknown. B. C. Renick[7] found in the Sierra Nacimiento of north-central New Mexico that the Santa Fe formation has been displaced up to a maximum of at least 8000 feet by faulting. Earthquake rifts and the recent Valentine earthquake in Trans-Pecos Texas perhaps indicate that the earth movements are not yet entirely at an end.

The Cenozoic volcanic activity in the Trans-Pecos province was in part either accompanied or followed by movements predominantly of faulting, with relatively gentle and broad folding and extensive tilting of the strata in the region northeast of the Mexican overthrust province. In the latter province, as we have already seen, much greater folding, with some thrusting, took place in this epoch. Very gently folded, broad synclines were made in the Diablo Plateau in the northern area and in the northern part of the Big Bend country of the southern area. The Diablo Plateau is bounded on the east by a fault, east of which the rocks have dropped into the trough, or "graben," of the Salt basin, which is bounded on the east at the north by the upfaulted eastward-tilted broad block of the Guadalupe-Delaware mountains. The southwestern margin of the Diablo Plateau tilts gently under the lowland of the Hueco Bolson, which is bounded on the west by an abruptly upfaulted complex of the Franklin Range, which extends from El Paso to beyond the New Mexico line. The volcanic rocks of the Davis Mountains are deformed into gentle parallel folds, with some faults at their northeast and southwest margins. Farther south the eastern and western rims of the Big Bend depression break off in many places through lines of downfaulting into adjacent lower country. At the south, in the Big Bend, strictly speaking, the central area of the sunken area is also cut by important faults and is folded as well.

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[7]Renick, B. C., Geology and ground-water resources of western Sandoval County, New Mexico: U. S. Geol. Surv., Water-Supply Paper 620, pp. 70-77, 1931.

The lines of Cenozoic movement perhaps follow in general those of the Laramide diastrophism. That the entire mountain area was uplifted several thousand feet during the epoch is probable, though the uplift dies out in gentle and long-continued east and northeast dips towards the Pecos River. The uplift has formed on the whole either plateaus of considerable extent, the rocks of which are in part tilted, gently folded, or faulted, or, as in the Franklin Range, a narrow, steeply-tilted, complexly-faulted block. The Franklin is a range of the type common in the desert region of the southwestern United States, while the plateaus are more similar to the Colorado plateau province. The center of the general uplifted area is the faulted Van Horn uplift, structurally the highest part of Texas.

There are, in addition to mountains and plateaus originating through folding and faulting, a number of other Trans-Pecos peaks, which are composed of intrusive igneous rocks or which were thrust up by igneous intrusive forces. Since the igneous intrusives are of the same general age as the eruptive or extrusive volcanic lava flows and are products of the same igneous activities, all the existing mountains, regardless of their nature or origin, can be assigned to a post-Laramide date.

The mountain-building forces exerted their greatest influence upon the topography either after the major movements had ceased or after a large share of them had occurred. During this time the whole Trans-Pecos mountain section of both Texas and New Mexico, as well as the adjoining section of Mexico, with the exception of the eastern slopes of the easternmost ranges, drained into a system of enclosed inter-range basins. If there was sufficient rainfall, these basins were occupied by fresh water lakes, but if the climate was dry, they had no drainage into the Gulf of Mexico. The Salt basin of Texas still exists as one of these self-enclosed basins without exterior drainage. The other intermontane basins of Trans-Pecos Texas subsequently have been drained by the Rio Grande and its tributaries, which have removed, by headward extension and erosive downcutting, the formerly existent barriers to exterior drainage. The higher mountains of the Rio Grande headwaters have much greater rain- and snowfall than the middle and lower parts of the river basin, so that the Rio Grande is usually a constantly flowing stream even though by far the greater portion of its course lies in the desert. It may be, therefore, that the river maintained its course throughout the last mountain-making epoch and hence greatly aided or entirely brought about gradual drainage of the basins, but, at any rate, one or more fresh water lakes occupied a part of its course above the Boquillas Canyon, in which the river now cuts across the Sierra del Carmen, the easternmost range.

The Trans-Pecos landscape has been constructed by the combined effects of the later Cenozoic mountain-making forces and the accompanying and succeeding erosion. The canyons, buttes, and mesas of the Edwards or Stockton Plateau, situated between the eastern or frontal mountain range and Pecos River, are sculptured by erosive forces as a result of the uplift and eastward tilting of the plateau during the making of the mountains.

MAJOR STRUCTURAL PROVINCES IN TRANS-PECOS TEXAS

Trans-Pecos Texas may be subdivided into two nearly equal portions, the northeastern plains and plateaus, and the mountain belt. Structurally, however, even considered broadly, further subdivision is necessary. Thus the northeast section is occupied by a great syncline, the Toyah basin, which extends eastwards across Pecos River to the margin of the Llano Estacado, southeastward to the Edwards Plateau, and northwestward into New Mexico. Southeast of the Toyah basin lies that part of the Edwards Plateau which extends westward across Pecos River with gradually increasing altitude until it reaches the mountains. To the south of this western extension of the Edwards Plateau there is an area in southern Terrell and southwestern Val Verde counties which is the northwestern end of the Nueces River or Eagle Pass syncline of the Gulf Coastal Plain province. The mountain belt can be separated into two groups, lying on either side of a great depression known as Salt basin extending approximately north-south from New Mexico nearly to the Rio Grande. East of the depression is the line of the eastern or front ranges, comprising from northwest to southeast, in order, the Guadalupe, Delaware, Apache, Davis, Barilla, Glass, Mount Ord, Del Norte, Santiago, and Carmen ranges. West of the Salt basin and east of the Hueco Bolson the mountains known as the Hueco, Finlay, Diablo, Carrizo, Beach, and Baylor are all linked structurally with the Diablo Plateau. The ranges south and southeast of the Diablo

Plateau are really parts of the western rim of the Salt basin and its southward extension. In order, beginning at the north, they are the Wylie, Chispa, Van Horn, Tierra Vieja, Chinati, Cienega, and Bofecillos mountains. South of the western margin of the Diablo Plateau is a region characterized by overthrusts from the southwest. This region, including the Malone, Quitman, and Eagle mountains, may be known as a part of the Mexican overthrust province.

In traversing the mountainous belt, the Texas and Pacific Railway follows a zone of passes and gently sloping territory which forms an important boundary between types of structure, that on the north of these passes differing from that on the south. Thus divided, northern Trans-Pecos Texas west of the plains consists of three relatively uplifted highland areas, named, from east to west, the Delaware-Guadalupe mountains, the Sierra Diablo-Diablo Plateau with the Finlay and Hueco mountains, and the Franklin Mountains. Between the Delaware Mountains and the Diablo Plateau is Salt basin, already referred to as part of a north-south regional depression. Between the Diablo Plateau and the Franklin Mountains is another lowland, the Hueco Bolson. The southern Trans-Pecos mountain province, comprising two-thirds of the Trans-Pecos Texas mountains, must be subdivided further, as will be done on later pages and as shown on the accompanying map (Pl. IV, in pocket).

TOYAH BASIN

The Toyah basin was named by R. T. Hill.[8] He classed it as one of the bolson plains, stating that "The term 'bolson', derived from the Spanish word signifying a purse, is an apparently level valley, usually slightly depressed toward the center, and inclosed by mountains, ordinarily without drainage outlet. These plains, or 'basins', as they are sometimes called, are largely structural in origin." He adds that "Along the eastern front of the Trans-Pecos mountains there is a series of basins that may probably once have been inclosed bolsons, the configuration and history of which have not yet been fully studied. . . . The larger and more northern of these, which lies almost wholly in New Mexico, may be called the Roswell basin, and the more southern one, which lies in Texas, the Toyah basin."

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[8]Hill, R. T., Physical geography of the Texas Region: U. S. Geol. Surv. Topo. Atlas, folio (No. 3), pp. 8-9, 1900.

The older writers,[9] subsequent to Hill, continued to use the term Toyah basin in the topographic or physiographic sense. It was not until the last decade that the fact became known, as the result of deep borings, that it is also a broad and deep structural basin. The underlying bed rocks are covered by surface alluvial and eolian deposits which served to conceal the true structure. The names "Delaware basin" and "Castile basin" have been used for the structural basin underlying the Toyah topographic basin. The use of two or more names for the same basin is confusing and especially so to those who do not have an intimate knowledge of the area. Therefore, the structural basin is called in this paper the Toyah, although it is realized that this decision will not be satisfactory to all.

The Toyah structural basin, as herein used, covers the whole of Reeves and Loving counties, the northern half of Pecos County, and parts of western Winkler and Ward counties in Texas, and extends northwards into New Mexico. It is bounded on the west by the Delaware and Guadalupe mountains, on the southwest by the Davis Mountains, on the south by the Glass Mountains, and on the southeast by the Edwards or Stockton Plateau. Its eastern boundary is the anticlinal uplift in Ward and Winkler counties, Texas, and in Lea County, New Mexico, on which is situated a line of oil fields.

The trough of the Toyah synclinal basin extends from approximately the middle of the Reeves-Pecos county line northwards to along the line between Winkler and Loving counties. It is thus arcuate, with convexity to the east. The Comanche rocks are downfolded into the basin, and there is some physiographic evidence which indicates that it was subject to folding during the Cordilleran orogeny. The basin is markedly asymmetric, its trough being near the eastern margin, the amount of uplift on its western flank being much greater than on the eastern.

EASTERNMOST RANGES

The eastern belt of ranges begin at the New Mexico line with the southeastern end of the Guadalupe Mountains, which reach their culminating summits in the great westward-facing cliff of Capitan

[9]Richardson, G. B., Report of a reconnaissance in Trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23 (Min. Surv. Ser. Bull. 9), 119 pp., 1904. Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of Trans-Pecos Texas: Univ. Texas Bull. 1753, pp. 61–172, 1917.

Permian limestone in Texas, although most of the range lies in New Mexico. South of the southernmost point (Guadalupe Point), the mountain ridge becomes lower and is known as the Delaware Mountains. It extends southwards to the complex of parallel and wedge-shaped downfaulted blocks of Seven Heart Gap, south of which are the Apache Mountains, extending nearly to the Texas and Pacific Railway line. The exposed sedimentary rocks of the three ranges are entirely of Permian age.

The Texas and Pacific Railway follows a broad gap between mountains. This gap is flanked on the south by the Davis Mountains, in which volcanic rocks are dominant. The northern and eastern limits of the Davis Mountains are easily defined as the edge of escarpments of volcanic rocks resting upon a Cretaceous sedimentary basement. Their northeastern margin is a lower range, mainly of volcanic rocks, known as the Barilla Mountains, in part separated from the greater range by the valleys of some of the upper courses of Toyah and Limpia creeks. The western and southern limits of the Davis Mountains are very indefinite, since their volcanic rocks and characteristic topography extend far down the eastern flank of the Big Bend depression, the dip of the rocks finally carrying them under a flattish-surfaced mantle of their own waste products. On the south-southeast, the lower, flattish area of Green Valley limits the mountains, but directly south the volcanic rocks form scattered mesas and gently dipping cuestas most of the way to the Rio Grande.

Farther to the south, beyond the line of the Southern Pacific Railroad, the topography of the eastern range becomes more definite, being confined to the eastern and higher rim of the central area of lower structure. The structure of the rim, however, is complicated by folding and faulting. At the north, in the Mount Ord range proper, is a westward-dipping cuesta with steeper slope or scarp side on the east. The southern continuation becomes even narrower, although the structure is more complicated, in the Del Norte Mountains, which extend as far south as Del Norte Gap. Between Del Norte Gap and the Southern Pacific, the east range extends north and south. The Santiago Range begins at Del Norte Gap and trends first southeast, then due south, and again southeast to Dog Canyon, where it turns abruptly to a little west of south and ends. To the southeast comes a broader range, consisting of a series of fault blocks of Cretaceous limestone, the Sierra del Carmen, which is crossed by the Rio Grande in a series of canyons below Boquillas. The Marathon basin has been eroded out of a former broad dome of Cretaceous rocks situated east of the Mount Ord, Del Norte, and Santiago mountains. Its northern rim (the Glass Mountains) is a complicated north-northwestward dipping cuesta of Permian limestone.

GUADALUPE-DELAWARE-APACHE MOUNTAINS[10]

The structure of the Delaware-Guadalupe Mountains is comparatively simple, consisting of a broad eastward-tilted block, with western scarp overlooking the depressed area of the Salt basin, and a long and gentle eastward dip-slope, which, as the western limb of the Toyah syncline, extends eastward to beyond Pecos River. The general trend of the scarp is about 15° west of north, although it is not so straight-lined in the Delaware as in the Guadalupe Mountains.

The lowest formation, the dark Bone Springs (Leonard) limestone, is exposed at the base of the Guadalupe in the Texas part of the range and for some distance northward into New Mexico. This limestone is exposed at the west base of the Delaware Mountains for some 25 miles southward beyond Guadalupe Point, the southern end of the Guadalupe Range. The Bone Springs limestone dips gently northwards along the scarp into New Mexico and southwards near the south end of its exposure in the Delaware Mountains. This limestone reaches its greatest altitude in the vicinity of Bone Springs ("Bone Springs arch"), between Guadalupe Point and the New Mexico line. In other words, the Texas part of the Guadalupe and the northern 25 miles of the Delaware Mountains have the structure of a gentle arch or anticline, bisected along its axial line by the frontal fault on the north at the base of the scarp. The fault plane is exposed at the foot of the bed rock exposures one mile south of Guadalupe Point, the fault plane dipping 70° to 80° to the southwest and displaying slickensides, slightly inclined to the

[10]Among publications relating to structural features in the Guadalupe, Delaware, and Apache mountains cited in the bibliography of Vol. I are the following: Baker, 44 and 48; Blanchard and Davis, 122; Cartwright, 201; Darton, 394a and 395; Girty, 589 and 590; King and King, 932; King, P. B., 936g; King, R. E., 930; Osann, 1162; Richardson, 1304 and 1314.

vertical, and vertical sheets of brecciated rock. The fault plane forms a small scarp 30 feet high and from 60 to 80 yards in length. Farther north at the westernmost base of the scarp, about one and one-half miles southeast of Bone Spring, the fault strikes N. 25° W. (magnetic ?) and dips about 75° to the southwest. A block of thin-bedded Bone Springs limestone 5 feet in width is here included between fault walls, in which there are calcite veins. The strata plunge about 600 feet to the southward from Bone Springs to Guadalupe Canyon.

The great scarp of the Guadalupe Mountains rises from 4500 feet to more than 5000 feet above Crow Flats, the main "sink" of Salt basin. It is capped by about 2000 feet of Capitan limestone, which forms one of the most impressive cliffs in the country. The rim edge of the scarp top has receded, on an average, fully a mile eastward from the frontal fault at the base. Northwards the fault passes into a plunging anticline. South of Bone Springs Canyon, the strata in part arch over to the west before being downthrown by the frontal fault, and the higher strata of the range are exposed in the downthrown block in a belt of foothills in which the strata dip from 10° to 30° southwest. The structure, therefore, of the Texas part of the Guadalupe Range is that of an unsymmetrical anticline with steeper dips on the west flank and with a faulted axis with downthrow to the west. Another fault, east of the frontal one, occurs at the west base of a high scarp in New Mexico and extends a short distance into Texas. The summit Capitan limestone probably was not deposited beyond the southeastern scarp of the Guadalupe Range.

Recent detailed structural mapping by Dr. Philip B. King has proved that a number of parallel and sub-parallel faults to the main frontal fault cut the strata in the southern or Texas portion of the range and that the foothill fault block bordering to the west the great frontal fault is broken into a mosaic by oblique faults.

The true structure of the Delaware Mountains is not so certainly known. The rocks of this range are less resistant to erosion than the limestone capping the Guadalupe Mountains. Also the elevation is less. The rocks in the long eastward slope of the Delawares dip 1° to 5° east-northeast, but at the western margin they turn over in places and dip as high as 15° west-southwest. Richardson[11] states that there is a western frontal fault marked by a downthrown foothill-disturbed zone and says the faulting is older than in the Sierra Diablo on the opposite side of Salt Flat. But the fact that the range is lower and the rocks of less resistance would argue against a greater age for the deformation, since a more advanced stage of erosion would be reached under such conditions. Nor has a frontal fault, at least of any great amount, yet been proved. At places, broad arching is visible in the western scarp. The front line of the western scarp is markedly sinuous and mainly carved by erosion. Possibly most of the range is a broad arch, probably with somewhat steeper dips on the west flank, but the arch is now greatly eroded. In the interior of the northern half of the range, step-faulting is known, the faults being relatively short, of north-northwest trend, and with relatively small amounts of downthrow to the west. Towards the south, faults of the same nature, with variable throw, trend east-west. Eastward, dips vary considerably in amount within short distances. North-northwest of Seven Heart Gap there are diverse dips and a small anticlinal fold.

Seven Heart Gap is in a compound downfaulted block between the southwestern Delaware Range on the northeast and the Apache Mountains on the southwest. The faults trend east-southeast, extending to an area of igneous rock at the corner of Culberson, Jeff Davis, and Reeves counties. The fault zone continues farther southeast, broadening out into a zone of folds and faults in the Barilla and northeastern Davis Mountains, in which the faults occur mainly at the lower northeastern edge of the foothills.

The Apache Mountains exhibit a much dissected fault scarp on the northeast, the strata having low westward dips in the north part, the dips swinging more to the south as the town of Kent is neared. The Cretaceous flanking the western, southern, and eastern margins of the Apache Mountains has the structure of a broad half dome at the southern end of the Delaware-Apache uplift.

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[11]Richardson, G. B., Description of the Van Horn quadrangle: U. S Geol. Surv , Geol. Atlas, Van Horn folio (No. 194), p. 7, 1914.

DAVIS AND BARILLA MOUNTAINS[12]

The eastern ranges are not structurally prominent in the Davis Mountains, although the altitude of that group is no lower than the neighboring range. In contrast with the uplifts of the Delaware Mountains at the north and the Marathon dome-Mount Ord Range at the southeast, the Davis Mountains are an area of lower structure, in which Upper Cretaceous and overlying volcanics form the surface rocks, while the igneous rocks are responsible for the high and rugged topography of mesas and sharp peaks. Lava flows are predominant in the northeastern section, and intrusives are more common south of the latitude of Fort Davis. The lava flows form prominent bounding scarps on all sides, but the boundary is ill-defined at the south unless we include in the range all the cuestas of lava and volcanic ash north of the Big Bend sunken block. On the west it is scarcely justifiable to separate the mountains and hills of igneous rock between the south base of the Wylie Mountains and the Southern Pacific Railroad between Chispa and Valentine from the main mass, although a lowland alluviated strip intervenes.

The mountains at the north end are a gently south-southwestward dipping lava-capped cuesta, in which volcanic rocks lie on Middle Cretaceous (later Comanche) and Upper Cretaceous strata, the Cretaceous topping the Permian rocks, which dip southwards from the Apache Mountains. The cuesta passes into a broad gentle northwest-southeast syncline at the south, the trough of which lies about midway between the northern escarpments and Sawtooth Mountain. On the northeast flanks, the complexly downfaulted block between the Delaware and Apache mountains passes southeastward into northwest-southeast gently dipping anticlines and synclines, with some faults with northeastern upthrow. The folded area extends as far as the northwestern foot of the Marathon dome in the Glass Mountains. Nothing is known of the structure from the folded area south to the 30th Parallel, except that the eastern cuesta, from the Southern Pacific Railroad south, dips very gently westward. Intrusives, doming either volcanics or underlying sediments, are known halfway between Alpine and Fort Davis; from 10 to 15 miles west of Fort Davis on the Valentine road; in the Summit or Sawtooth

[12]Among publications relating to the Davis and Barilla mountains cited in the bibliography of Vol. I are the following: Baker and Bowman, 44; Darton and King, 396b; Osann, 1162.

Range; in the vicinity of Paisano Pass; around Altuda Mountain; at Cienega Mountain; in the Del Norte and Santiago ranges; and in Green Valley. Most of the intrusives appear to be in a belt extending southeastward from Sawtooth to Cienega mountains. There are other intrusives between Valentine and the Wylie Mountains. The trough of the main structural downwarp of the volcanic rocks is followed by Alamito Creek from near Marfa southwards to the vicinity of Casa Piedra station on the Santa Fe. The Davis Mountains occupy an extensive structural downwarp which becomes apparently more extensively faulted to the southwest of the Santiago Mountains and towards the Big Bend sunken block.

MARATHON DOME[13]

The Marathon dome, the central area of which is now the eroded lowland of the Marathon basin, forms an area of relative uplift from the line of the Santa Fe (Orient) Railway on the north to the synclinal area separating the dome from the Sierra del Carmen on the south-southeast. The western flank of the Marathon dome is the eastern flank of the Big Bend depression. The strata of the dome show the effects of every deformation which has affected the Texas region since before the beginning of the Ordovician; hence the dome furnishes an epitome of the diastrophic history of the state, and. indeed, of a much more extensive area of the Southwest.

The known depositional history of the Marathon area begins in the Upper Cambrian. There is a fairly full, though probably not entirely uninterrupted, history of deposition until late in the Ordovician, when a break in sedimentation, perhaps contemporaneous with the Taconic disturbances of the Acadian region of New England and eastern Canada, probably occurred before the deposition of the Maravillas formation. There was deposition again in latest Ordovician or earliest Silurian times, when the Maravillas chert was deposited. During most or all of the Silurian, no deposition occurred, and just how much of Devonian and Mississippian time was occupied in the deposition of the Caballos novaculite is not known, although the chert and novaculite deposits may have accumulated very slowly, especially since they contain no detrital sediments. Then

[13]Among publications relating to the Marathon dome cited in the bibliography of Vol. 1 are the following: Baker and Bowman, 44; Baker, 47 and 56a; Darton and King, 396b; Hill, 800; King, 936, 936a, and 936g; Sellards, 1435; Sellards and Adkins, 1442

followed a time of non-deposition, in which the Caballos sediments were in part eroded, followed by deposition of the Tesnus, the sediments of which were derived in part from a distant recently uplifted land mass of crystalline metamorphic and igneous rocks. From the beginning of Tesnus time until far into the Permian, there were important diastrophic movements, which reached their greatest intensity in later Pennsylvanian. These movements belong to the Variscan mountain-making epoch. During this time about 20,000 feet of rocks were deposited in the Marathon area, the deposition being interrupted by at least three great breaks marked by unconformities in the sediments. During earlier Mesozoic time the region was land, subject to great erosion, which developed a peneplain by the time the Cretaceous sea began its spread from the south over the area. Sedimentation then ensued until near the end of the Cretaceous, when the Laramide deformation, forming structural axes at right angles to the Variscan, occurred. The Laramide mountain-making epoch was followed by great erosion before the volcanic rocks covered at least the western fringe. In the later Cenozoic, the volcanic rocks were tilted, folded, and faulted in a final diastrophic epoch, followed by the great erosion which continues at present. Such a complicated history has inevitably produced a great diversity and complexity in structure. In fact, almost every known type of structure is found somewhere within the confines of the Marathon dome.

The Variscan structures are found in the central area of the basin, where they have been exposed by the unroofing of a dome formed in later time. At the extreme northeast the fold axes trend only slightly south of west, but in the larger part of the basin they trend southwest. For the most part the strata are isoclinal and dip steeply southeast. They are cut by numerous thrust faults, the most extensive of which is the Dugout Creek overthrust near the northwest margin of the exposures. The overthrusts advanced from the southeast towards the northwest. The overthrust planes were in many instances themselves folded by later movements. The highest structures are in two very complex anticlinoria in the southwestern part of the basin, the Marathon anticlinorium on the northwest and the Dagger Flat anticlinorium on the southeast. These are bounded and separated by synclinorial belts. The amount of uplift is less in the eastern part of the basin, where only the younger or Mississippian-Pennsylvanian rocks are now exposed.

The uppermost Pennsylvanian and all the Permian strata were deposited after the major folding and thrusting. These rocks border the older Paleozoic strata on the northwest and outcrop in the Glass and Del Norte mountains. There are indications that they never were deposited much farther southeast than their present limits but overlapped the flank of the older mountain chain. There is an important unconformity in the lower Permian at the junction of the Hess and Wolfcamp formations, and another at the base of the Bissett formation. There were also tilting and oscillations during the deposition of the Permian. The Permian sediments were tilted after Permian deposition and perhaps both before and after Upper Triassic time.

Structures on the Marathon dome produced by the Laramide and later Cenozoic deformative epochs are hard to differentiate, since the volcanic series, deformation of which occurred in the later Cenozoic, is found only relatively low down on the western flanks. However, Laramide deformation is known by an important angular unconformity between the Cretaceous and the overlying volcanics on the western flanks. On the other hand, the physiographic development, as well as the westward tilting of the volcanics, demonstrates that mountain-making movements also took place late in the Cenozoic. The overturned folds and overthrusts of the western rim can now be stated merely to be post-Cretaceous since no volcanic rocks are present in this belt.

The western rim comprises the Del Norte Mountains or Mount Ord Range at the north with nearly north-south strike. The structural lines beyond Del Norte Gap in the Santiago Range have more of a northwest strike. The latter range ends in the synclinal area a short distance southeast of Dog Canyon of Calamity Creek. In these mountains, which lie in the western asymmetric flank area of the Marathon dome, the dips are generally steep or the strata overturned.

The Marathon dome at the northwest contains the northwest-elongated dome-like Altuda Mountain uplift, with an intrusive plug at the south which tilts the strata north, northeast, and northwest. A large fault at the south has downthrow to the east, and probably the Altuda Mountain uplift is bounded to the east by another fault with eastward downthrow. Strata dip westward into the fault, which forms the east limit of the south half of the dome. Another dome with steeper dip on the west flank, and quite possibly underlain by an intrusive, comes next on the south, and the two domes are flanked to the east by several broad, low, north-northwest-trending anticlines, to the south of which is the main, steep, westward-dipping monocline of the Del Norte Range. In this range, at the north, the dips are vertical or the strata overturned, but the monocline passes into a westward overthrust, 5 miles north of Doubtful Canyon, with flank dipping 70° E. The narrow overturned or overthrust belt continues south and then southeastward to beyond Dog Canyon. Perhaps the greatest amount of overthrusting is near Persimmon Gap where the Tesnus is stated to be in contact with the Rattlesnake (Taylor). From Del Norte Gap to beyond Dog Canyon, a belt of folded and in part faulted Cretaceous, with strikes varying from north-south to northwest-southeast, lies to the east of the overturned and overthrust belt. The strike swings to the southwest at the southeastern end of the Santiago Range.

Westward from the overfolded belt the dip becomes gentle to the west or southwest. This flank has a number of intrusives. A normal fault of large displacement, striking north-northwest and with upthrow on the southwest, extends between the intrusive masses of Santiago Peak and the Rosillos Mountains. The fault swings to the west at a point south of Santiago Peak. The upthrown scarp of this fault forms the west wall of Chalk Draw valley.

Overthrusts towards the Big Bend depression occur on both its eastern and western margins. There has, therefore, been a shortening movement and a tendency for higher structural areas to override the downwarped strata, during both the Laramide and later Cenozoic movements. Or else there has been underthrust outwards, perhaps caused by expansion by heat from the igneous rocks of the Big Bend depression, with a later sagging of the central, lower, area upon contraction caused by cooling of the once molten magma.

On all sides excepting the west and southwest, the Marathon dome is flanked by gentle outward dips. The Permian strata of the Glass Mountains on the north and northwest have north to northwest dips, usually of about 10°, although a maximum of 20° is noted at some points. Intrusives cut these strata in the area north and northeast of the Iron Mountain intrusion. The eastern and southern flanks of Cretaceous strata have dips of 2° to 5°. There is a subsidiary anticline in the Cretaceous at the southeast corner of the dome, which strikes and plunges southeast with a dip of about 10° on the northeast flank. A fault, running west of south, leads from this to a point west of the volcanic peak of Dove Mountain and perhaps extends across Maravillas Creek. A number of intrusives flank the dome on the south, and basic lava outcrops flank the Santiago and Carmen ranges on the northeast.

A system of northwestward-trending faults has broken the Glass Mountains and Marathon basin into a large number of fault blocks. About 40 of these faults are known in the Glass Mountains. The average strike of the faults is N. 30° W. The faults of major displacement are all downthrown to the northeast, but the minor faults have downthrows to either east or west. The fault throw varies from 50 to 500 feet or more, the largest displacements being in the western area. The Hess ranch horst, 5 miles northeast of Iron Mountain, is an oval area, elongated east-west, bounded on all sides by faults, and uplifted at least 2000 feet. It is flanked on the south by an intrusive which has caused part of the uplift.

The Sierra Madera is a small area northeast of the Glass Mountains which has been strongly and abruptly upthrust. It is both radially and tangentially faulted and has probably been thrust up by an intrusive. Locally the strata are vertical or overturned.

Bissett Mountain, at the west end of the Glass Mountains, is another dome, which, like Sierra Madera, has undergone uplift both before and after the Cretaceous.

MOUNT ORD, DEL NORTE, SANTIAGO, AND CARMEN RANGES[14]

These ranges form, orographically, a nearly continuous line, which makes the easternmost range of conspicuous summits. The names of Mount Ord and Del Norte have been used for the same range, but it is perhaps preferable to restrict the name Del Norte to the single and narrow ridge, structurally a unit, which extends

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[14]Among publications relating to the Mount Ord, Del Norte, Santiago, and Carmen ranges cited in the bibliography of Vol. I are the following: Baker and Bowman, 44; Baker, 47; King, 936; Osann, 1161.

from southeast of Altuda Mountain southward to Del Norte Gap on the Marathon-Terlingua road. Then the Mount Ord Range can be more precisely defined as the westward-dipping escarpment and cuesta just west of the Del Norte and extending from Strobel siding on the Southern Pacific at the north to the wind gap just north of Elephant Mountain at the south.

The Santiago Range continues the asymmetrical, overturned or overthrust structure of the Del Norte Mountains first southward and then southeastward to its end beyond the water gap of Dog Canyon. The Mount Ord, Del Norte, and Santiago ranges make up the west flank of the Marathon dome and are described with that structure.

The front range widens south of the Dog Canyon, and there the structure changes to the fault blocks of the Carmen Range, which extends thence to beyond the Rio Grande. The Carmen Range (Sierra del Carmen) will be considered with the Big Bend of the Rio Grande.

FLANK FOLDS EAST OF THE CARMEN RANGE AND SOUTH OF THE MARATHON BASIN

The Marathon dome is flanked on the south by a broad synclinal basin with west-northwest strike. Nearly all, if not all, of the basin is crumpled into minor folds. The basin is bounded on the south by a high, broad anticline crossing the Rio Grande just below the mouth of Maravillas Creek. This anticline is separated from the northeastern foot of the Carmen Range by a fault with downthrow on the northeast. The western flank of the anticline is cut by strike faults into slices with eastward dip and downthrow to the west. There are three more northwest-trending anticlines crossing the Rio Grande between the mouths of Reagan Canyon and San Francisco Creek. These also are cut in part by strike faults. Northeast from San Francisco Creek the prevailing dip is gentle to the northeast, but some gentle folding continues eastwards as far as Del Rio and also north of the Glass and Davis-Barilla mountains. These represent the gradual dying out to the northeastward of the Cordilleran movements.

SALT BASIN[15]

The Salt basin can be aptly termed a "rift-valley," provided that the word "rift" is not interpreted in a too literal sense.[16] The term "rift valley" is fitting and pictorial and is useful in both structural geology and physiography. But, unfortunately, Gregory has sought to give it a tectonic or dynamic interpretation which is as yet quite questionable. He thinks the East African, Red Sea, and Palestine rift valleys are formed by a stretching of the outer crust and a dropping in or down of the long, narrow rift valley blocks. Wayland and Willis, on the other hand, have interpreted some of the East African rift valleys as produced by compression and bounded by scarps of thrusts from opposite directions, towards each other. There is a third alternative, namely, that the entire region has been uplifted differentially—the rift valleys less than their bounding highlands. Lofty plateau blocks of pre-Cambrian rocks, like Ruwenzori, appear to have been uplifted (upthrust) or else their surroundings have been greatly downfaulted. Still a fifth alternative is that the "rifts" are formed by the removal of molten rock from beneath, which appears to be the most probable explanation for the rift-basin lakes in the state of Jalisco, Mexico. It is conceivable that all these types of movements are found within the Rift Valley province. So far, geology has found no proof of either absolute uplift or absolute depression; it knows for certain only relative movements.

A sufficient reason for using the term "rift valleys" in Trans-Pecos geology is found in the fact that Trans-Pecos Texas and New Mexico is a structural and physiographic province possessing the features of East Africa, the Red Sea, and Palestine. The two have broad, relatively uplifted, plateaus which exhibit the same structures and the same physiography as a consequence of the structure.

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[15]Among publications relating to the Salt basin cited in the bibliography of Vol. I are the following: Darton and King, 396b; Richardson, 1304 and 1314.

[16]J. W. Gregory (in "The Rift Valleys and Geology of East Africa," London, p. 18, 1921) originally used the term "rift valley" in the following sense: "That these valleys were made by the sinking of the material that once filled them, between parallel fractures of the kind known as faults, is now generally accepted. They were not formed by the removal grain by grain, by rivers or wind, of the rocks which originally occupied them, but by the rock sinking in mass, while the adjacent land remained stationary; what is now the floor of the valley formerly stood level with the highlands on each side. For this type of valley I suggested the name of Rift Valley, using the term "rift" in the sense of a relatively narrow space due to subsidence between parallel fractures. Such valleys are known in many parts of the world, but that of East Africa may justly be called the Great Rift Valley, as it extends from northern Palestine to southern Africa."

The Trans-Pecos rift valley province of the United States has a length—from the northern end of the San Luis Valley of southern Colorado to the southern Big Bend of the Rio Grande—of 700 miles. It has a farther, but still unknown, extent into Mexico. The Pecos River may be taken as its eastern boundary and the eastern and southern edges of the Colorado plateau province as its western or northern boundary.

The difference between the Trans-Pecos province of New Mexico and Texas and the Colorado plateau province, when the latter is restricted to the originally defined area, is one rather of degree than of kind. The Trans-Pecos province is in general the more highly deformed and the more faulted. As R. T. Hill long since pointed out, it is possible to cross nearly the whole of the Trans-Pecos region, at the junction of the Trans-Pecos province with the Rocky Mountain province, "without crossing a single mountain range or treading upon strata which have been seriously disturbed, except by faulting in the vicinity of the Rio Grande." (The faults are in the Sandia Range, near Albuquerque, New Mexico.) Hill names this section the Corona Plateau, and its similarity to the real Colorado Plateau is, indeed, striking. Nevertheless, even the transitional zone of the Corona Plateau is separated from the Colorado Plateau by an important downfaulted block in the valley of the Rio Grande, and this downfaulted block is occupied by the Rio Grande virtually across the entire state of New Mexico and is a real boundary between the Trans-Pecos and Colorado plateau provinces.

The essential "rift" or "graben" structure of the Rio Grande valley is likewise well exhibited in the Hueco Bolson and Big Bend in Texas, as well as from the north line of Presidio County downstream to Presidio. In the latter stretch, the river flows in a structural depression between the Rim Rock and the high, overthrust Chihuahua ranges.

The Salt basin very nearly merges at the north, in New Mexico, with another self-enclosed rift valley basin, the Tularosa or Otero basin, the two being separated by a low limestone ridge, the strata of which dip eastward into the northern end of the Salt basin. It is remarkable that in the most typical part of the Salt basin, which lies north of the 31st Parallel, fault line scarps bounding one side of the basin are faced on the opposite side by downwarps of monoclines in which the rocks dip towards and plunge under the alluvial floor of the basin. Thus, north of Latitude 31° 30′, the Diablo Plateau is built of strata which dip eastward in New Mexico and mainly northeastward in Texas. On the opposite side the boundary is the uplifted fault block of the Guadalupe-Delaware mountains. Between Parallels 31° 30′ and 31° the uplifted fault block of the Sierra Diablo makes the west boundary, and the east boundary at the north was originally more probably the axis of a now much eroded anticline which formed the summit divide of the southern Delaware Mountains. Farther south are the westward dipping slopes of the Apache Mountains fault block.

Another remarkable fact is that the complexly downfaulted Seven Heart Gap block, between the Delaware and Apache mountains, if extended across the basin would reach to the turn from north to west-northwest of the Sierra Diablo scarp at Latitude 31° 30′. This same turn, furthermore, is continued across the basin to the east by a turn in the same direction in the Delaware Mountain scarp. Farther east, within the Delaware Range, are a number of east-west faults. These turns are paralleled, farther south, by the east-west possible fault or, alternatively, the north monoclinal plunge, making the north foot of the Baylor Mountains. The Baylor Mountains are a block which is downfaulted from the Sierra Diablo at the west. One of the two salt lake "sinks," or subsidiary basins, of the Salt basin lies between the Baylor Mountains and the westward turns in the bounding scarps. The relationships suggest a depressed rectangular block within the basin, bounded to the north and south by east-west structural lines and crossed diagonally from southeast to northwest by a zone of faulting or downwarping subparallel to a fault farther south in the latitude of Van Horn, along which there has been pre-Ordovician as well as later displacement. The salt flat is thus not a simple rift as defined by Gregory but is a complicated graben.

The thickness of the basin fill is presumably great. A boring 10 or 12 miles north of the Figure 2 ranch was still in basin deposits at 1620 feet depth, and another, about 1½ miles north of Chispa section house and near the north edge of Chispa Creek flat, reached the base of the basin fill at 1180 feet.

BIG BEND OF THE RIO GRANDE[17]

For present purposes the northern boundary of the Big Bend country is taken, somewhat arbitrarily, as the parallel of 29° 30″ North Latitude. The south boundary is the course of the Rio Grande, and the northeast boundary, the northeast base of the Sierra del Carmen.

The Sierra del Carmen is a broad domical uplift, step-faulted, which forms the east boundary of the Big Bend depression. It continues into Mexico where it becomes higher both structurally and topographically. It is cut by the Rio Grande in a series of deep canyons below Boquillas. The general trend of the Texas portion of the range is south-southeast. The northern end of the range lies east of, and in *en échelon* arrangement with, the southern end of the Santiago Range, the two ranges being separated by a low broad syncline in which the surface formations are of the Fredericksburg-Washita series. The backbone range of the Texas section of the Sierra del Carmen is the Sierra del Caballo Muerto, which is the longest and highest of the individual ranges, and the one which extends farthest to the northwest. The Carmen Range in Texas consists of eight tilted fault blocks of Edwards-Georgetown limestone, downthrown to the east in a series of step-faults, the dip of the strata in the blocks dipping to the west in the blocks of the eastern flank. The fault blocks pass into anticlines to the northwest. It is possible that the faults are thrusts. In Mexico the main faulting has shifted to the west flank. The east flank of the Texas part is similar in structure to that west of the Rim Rock and south-southeast of the San Carlos dome. The west flank of the Carmen Range has a steep westward dip in blocks also downthrown to the east. However, the Muskhog Spring fault, which runs S. 23° E. to the west line of the farthest west Carmen fold (Alto Relex), has downthrow to the west, bringing the Rattlesnake (Taylor) against the upper Boquillas. Two small abrupt folds with the same trend are found about 200 yards east of the fault at Muskhog Spring, and another and smaller fault to the east brings up the lower Boquillas (Eagle Ford). Several faults with the same trend are found in the vicinity of Stillwell's ranch. Some faults of smaller displacement run nearly

[17]Among publications relating to the Big Bend of the Rio Grande cited in the bibliography of Vol. I are the following: Baker, 44; Hill, 807; Udden, 1626 and 1648.

at right angles, N. 80° E. One of these, southwest of McKinney's Spring, cuts across the north end of an intrusive sill. About one-half mile north of Muskhog Spring, there is a group of three faults about 200 feet apart. The one farthest south has the downthrow on the north side; between the other two is a narrow block upraised about 300 feet.

The southwestern boundary of the Big Bend depression is marked by the great Terlingua fault at the mouth of the Grand Canyon of Santa Helena, in which the Rio Grande crosses the southwestward-tilted cuesta of the Mesa de Anguila. The eastward-facing scarp at the mouth of the canyon is a cliff 1500 feet high, but the total displacement with eastward downthrow is there about 3000 feet and increases to the southeast in Mexico. The fault runs about N. 30° W., dying out to the northwest.

A sunken block lies between the great Terlingua fault and the axial summit of the Sierra del Carmen. The area, about 39 miles wide, lying between the Corazones and Rosillos mountains on the north and the Rio Grande on the south, has settled from 4000 to 6000 feet below its northeastern and southwestern boundaries. The sunken block is extensively, and in places violently, deformed by folding and faulting. The high intrusive and volcanic mass of the Chisos Mountains in the middle of it has uptilted and uplifted the Upper Cretaceous sediments around the intrusive margin.

The Rattlesnake Mountains are 7 miles northeast of the mouth of the Grand Canyon of Santa Helena and 7 miles east of Terlingua. To the northeast of them several nearly vertical faults cut almost horizontal strata into narrow blocks. Two of the faults are 900 feet apart and run about N. 22° W. They bound a block, uplifted 200 feet, on the north bank of Terlingua Creek about a mile south of the mouth of Dawson Creek. About a mile to the east there are two faults which have downthrow to the east and trend about N. 14° W. The throw on the eastern one is several hundred feet.

Burro Mesa is a block which has been downthrown more than any other part of the Big Bend, the lava complex having sunk some 2000 feet. The east side of Burro Mesa, west of the Chisos Mountains, is marked by a fault which extends from Rock Hut to south of Blue Creek in a direction of about S. 5° E. The west side of the mesa is an eastward-dipping monocline. Between the north end of the mesa and the south end of Christmas Mountains is a much disturbed belt. A fault crosses Cottonwood Creek about 3½ miles south and 1 mile east of Christmas Spring, with a course nearly due north-south, and a downthrow to the west of not far from 2000 feet, the Tornillo clays being brought down to the base of the Terlingua beds (Austin). This fault appears to turn to the west farther north and merge with the great fault following the west side of Christmas Mountains.

Southeast of the Chisos Mountains the Rio Grande, between the southernmost point of the Big Bend and the western foot of the Carmen Range, flows across four fault blocks. The three main faults on the Texas side of the river strike approximately north-south. The faulted anticlinal uplift of Mariscal Mountain is crossed diagonally by the Rio Grande in a canyon through the Middle Cretaceous limestone 1400 feet in depth. In Texas Mariscal Mountain is an unsymmetrical anticline plunging north-northwestward from the river for about 9 miles. Its west limb has locally been tilted into a vertical position. The eastern limb dips much less but is abruptly faulted at its east base by a fault running south into Mexico from a point about 3 miles north of the river. Several minor faults cut the anticlinal flanks. A block about 1½ miles wide, which has been downthrown between 1000 and 2000 feet, lies between Mariscal Mountain and the next uplift to the east, the Sierra San Vicente. The San Vicente Range, only the extreme north end of which enters Texas, runs north-south and is bounded on the west by the north-south fault forming the eastern boundary of the dropped block already noted. Another north-south fault, with downthrow to the west of between 500 and 1000 feet, crosses the river and extends some miles to the north of it just east of the old settlement of San Vicente.

At least three faults trending north-northwest cut the Rosillos Mountains, one in the arroyo of Cottonwood Spring, one east, and one west of Stroud's ranch. There is an east-west fault about a mile south of Stroud's ranch.[18]

Only exceptionally are the strata in the Big Bend sunken block horizontal. Dips more frequently are from 10° to 30°. Most of

[18]These and other localities can be found on the Chisos Mountains and Terlingua topographic maps.

the structures trend northwest-southeast. An anticline fully 3 miles wide, with northeast-southwest strike, lies west of the Rattlesnake Mountains. Another has an axis running S. 10° E. from Indianola Peak. Several northwest-southeast folds are found between the Chisos Mountains and Boquillas post office. The axis of an important syncline with the same trend is about midway between McKinney's and Neville springs. Banta Shut-In is on the southwest edge of a quaquaversal dome. The dip is quite uniformly to the south and east for 3 miles to the southeast of Maverick Mountain. The strata dip away from the fault on the east side of Burro Mesa. In Cottonwood Creek, a mile east of Chisos Pen, the block on the west side of the fault dips gently west and the block on the east is tilted away from the fault.

Hayes Ridge, the easternmost spur of the Chisos Mountains, is a nearly east-west anticline. North and northeast of Moss Wells the Chisos beds dip to the north, and south of Paint Gap Hill the Rattlesnake beds often pitch to the south.

Udden,[19] who is the authority on the Big Bend sunken block, remarks that if this block is divided into two halves by a straight line midway between the Terlingua fault and Sierra del Carmen boundaries, and nearly parallel with the former, this line will connect the three greatest deformations in the block, namely, the Christmas Mountains at the north, the Chisos uplift in the middle, and the Mariscal Mountains farthest south.

The Christmas Mountain fold is an elliptical domical uplift about 5 miles long and 4 miles wide, with longer axis N. 36° W. The maximum uplift in the lower Cretaceous limestones amounts to at least 4000 feet. The dome is fractured on the west side by several faults, and this side has an abrupt slope which is locally a vertical scarp. The principal fault at the south end is marked by a vertical cliff and associated with extensive calcite-filled fissures. The uplift is probably laccolitic.

The most violent of the deformations in the Big Bend sunken block is an abrupt fold caused by the intrusion of the "Rim Rock" of the Chisos Mountains, either in the form of an enormous plug or an unusually high laccolite. Nearby horizontal strata on the west

[19]Udden, J. A., A sketch of the geology of the Chisos country: Univ. Texas Bull. 93, 101 pp., 1907.

side are thrown into small but abrupt folds near the vertical wall of the mountain. On the south the sediments end abruptly against the igneous mass. On the east and north sides the sediments have been elongated into a half arch bending over the top of the "Rim Rock" intrusion, and from the north the sediments rise along a sharp contact at an angle of 75°. The total amount of uplift in these sediments (Eagle Ford) is about 7000 feet. Possibly the intrusive mass is more properly a bysmalith, or in part a volcanic neck. Udden[20] remarks:

> The whole round cluster of peaks, including an area ten miles in diameter, is a remnant pedestal under a volcanic pile, protected from erosive destruction by the endurance of the ancient cone, which once covered it and is now all but wholly removed. The two "rim-rocks" and other scattered laccolitic masses are the roots of the cone itself, or, to carry the comparison further, they are tuberous swellings on these roots, now more or less uncovered by erosion. What we find in the Chisos Mountains today is then the structure developed at a depth of several thousand feet under the surface of ancient lavas. These lavas were at least in part forced up through fissures in the strata which are now exposed.

A number of laccolitic uplifts are found in the sunken block. Such are Maverick Mountain, Rosillos Mountains, the mountains around Stillwell's ranch north of Banta Shut-In, the northeast projection of the Chisos Mountains, Corazones Peak, and a number of the smaller mountains between the Solitario and the Chisos, although some of the latter are probably plugs. Sills and dikes are particularly abundant in the Chisos peripheral area, and dikes radiate toward the southeast from the Christmas Mountains.

Long Draw, extending north-northwest of the present town of Terlingua, is a rift valley 9 miles long and from 1 to 2 miles wide. The vertical downward displacement of this sunken block is from 1500 to 2000 feet below the adjacent Reed Plateau on the south, and from 500 to 1000 feet below the more closely folded area on the north. Two parallel west-northwest anticlines flank the sunken block on the northeast. These plunge southeast in the vicinity of the Chisos Mine. Nearby in Grace Canyon, a block about 300 feet square has been dropped about 500 feet, possibly by collapse of the roof of an underground cavern.

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[20]Udden, J. A., *op. cit.*, p. 87.

Reed Plateau dips gently southwest in its summit portion, the dip steepening on the southwest flank. The axis of a low north-south anticline runs along Terlingua Creek near the line between Sections 248 and 229, Block G-4; this has the higher dip on the eastern limb. A short distance south and 3 to 4 miles east of Terlingua is Cuesta Blanca, on the north side of which the Rattlesnake (Taylor) is faulted down against the Boquillas along a fault line, concave to the north but in general running east-west. Tres Cuevas Mountain and Sierra del Cal lie from 5 to 8 miles west of Terlingua. They form an arc of a southward dipping monocline, concave to the north and cut to the north by small west-northwest faults. This arc is part of the southwest flank of the larger Solitario anticline.

The uplift of the Solitario is crossed by the Brewster-Presidio county line 10 to 15 miles north of the Rio Grande. The dome is nearly circular and about 9 miles in diameter. It merges to the southeast into a lower broad anticlinal uplift with northwest trend. Since igneous intrusions are very common within the Solitario and since the most extensive igneous outcrop reaching from the center to the southern margin of the encircling rim may be the roof of a laccolite, the dome is probably caused by a laccolitic intrusion. A central lower area exposes much folded and faulted Paleozoic rocks. The Paleozoic strata are Cambrian, Ordovician, Devonian (?), and Carboniferous. The high encircling rim is made of outwardly-dipping Glen Rose to Georgetown Cretaceous strata, which on the inner margin have dips averaging close to 45°. The dips gradually flatten out towards the periphery. An intrusive outwardly-dipping sill of an acidic felsite-like rock, intruded into the lower Trinity, entirely circles the Paleozoic area just outside its margin.

The Solitario is the southwesternmost known appearance of the Variscan mountain system formed in Pennsylvanian time. The Variscan fold axes, though no doubt shifted about by the much later steep upthrusting, were here predominantly northeast-southwest.

The chief interest of the Solitario lies in its Paleozoic rocks. The Paleozoic rocks are hidden from view for 40 miles to the northeast and reappear in the Marathon basin where they are likewise greatly folded and faulted. Metamorphic cherty marbles and quartzites, possibly metamorphosed during the Pennsylvanian mountain-making or the much later igneous intrusion, occupy a small area just east of the center and are faulted up against the intrusive igneous rocks on the west. A central irregularly rectangular block, tilted in part at least to the south and bounded to east and west by faults running slightly west of north, is dropped down into the Paleozoic area. North, east, and west of this block are Cambrian and Lower and Middle Ordovician highly deformed strata; to the southwest the block is bounded by an area of steep southwardly dipping Upper Ordovician, Devonian (?), and Carboniferous (Tesnus) rocks; on its southeast the Tesnus shale has steep southeast dip. At the extreme west, northwest of the center of the dome, is a small area of Upper Ordovician and Devonian (?), which dips west. The area west of the center exposes closely folded Upper Ordovician, Devonian (?), and Carboniferous with west-southwest strike, cut by a northwest-southeast fault with downthrow to the northeast. The Paleozoic section, younger than mid-Ordovician, with southeast strike and northeastward dip, and limited on the southeast by a northeast-southwest striking overthrust fault, occupies a triangular area east of the county line at the northeast periphery of the Paleozoic area. The east and southeast area of Paleozoic strikes north of northeast and contains five belts of steeply dipping Upper Ordovician and Devonian (?) strata, separated by four belts of the Tesnus shale. Beginning at the Cretaceous contact at the extreme southeast and proceeding to the northwest across the strike, one finds first a syncline overturned on the southeast flank and then an anticline. The axial part of this anticline is a folded overthrust in which the highest Paleozoic exposed, the Tesnus, is overlain on both flanks by the Upper Ordovician Maravillas and the Devonian (?) Caballos. Subsequent erosion has exposed the Tesnus strata underneath the overthrust in a "window." Next to the northwest is a normal syncline in which the Tesnus overlies the Devonian (?). At the northwest base of this synclinal flank, the Upper Cambrian and Lower and Middle Ordovician are overlain by the Upper Ordovician Maravillas in the complexly deformed anticlinorium of the northern half of the Solitario. The southwestern limb of a syncline of Upper Ordovician and Devonian (?), with a fault contact on the southeast with the older Paleozoic, and another fault contact on the northwest with the Tesnus, occurs at the extreme northeast. Although the exact structure is not certain, this last syncline is probably a downfolded remnant of an overthrust sheet.

The broad anticline on which the Solitario stands continues south-southeastward to a syncline, which extends southeast from Lajitas Mesa until it meets a north-northwest-trending anticline. This anticline begins to rise about 2 miles south of Terlingua and plunges southeastward beyond Terlingua Creek. The anticline southeast of the Solitario is bounded on the southeast margin by the rift valley, or down-faulted graben, of Long Draw. This graben in ground plan is concave to the east. Another wedge-shaped down-dropped block extends from an apex east of Black Mesa southeast to the west foot of Reed Plateau. A northwest-southeast fault with downthrow to the southwest runs about a mile to the northeast of Hen Egg Mountain. There are two other narrow depressed areas with northwestward strike, one followed by Terlingua Creek above Crenshaw's Camp, and the other by Saltgrass Draw. Cuesta Blanca lies in an upthrown block striking slightly north of west.

The great Terlingua fault is the southwest boundary of a down-dropped block which has its apex about 2 miles east-southeast of Comanche Spring, the sides of the block becoming parallel farther southeast, and the eastern bounding fault dying out beyond Terlingua Creek. This block has another sub-parallel fault, with northeastward downthrow, cutting its southeastern half, and an east-northeast fault, with downthrow to the north-northwest, cutting partly across its northern half.

The Mesa de Anguila, southwest of the great Terlingua fault, is a southwestward-tilted block, cut at the northwest by two northwestward faults sub-parallel with the great Terlingua fault. The one to the northeast has downthrow to the northeast, and the other, downthrow to the southwest. The northeastern fault swings around to the west until it meets the southwestern one at a point at the north end of the Mesa de Anguila about a mile east of the Rio Grande. Farther east a northeastward-striking cross fault connects the great Terlingua fault with the northeastern of the two faults just described. Almost on a line which would be the west-northwest continuation of the southwestern Mesa de Anguila fault is another fault, with downthrow also to the southwest, which crosses Fresno Creek about one-half mile above the Rio Grande. The upper volcanics, covering a large area west of Fresno Creek canyon, may be among the youngest in Trans-Pecos Texas.

DIABLO PLATEAU AND ASSOCIATED MOUNTAINS[21]

The Diablo Plateau is essentially a broad synclinal area of gently dipping strata, extending from the high escarpment of the Sierra Diablo, northwestwards into New Mexico, and bounded on the east by the lower flat of Salt basin, on the west by Hueco Bolson, and on the south by the broad gap crossed by the railways. The Hueco Mountains uplift forms its northwestern margin, the Finlay Mountains dome its southwestern margin, and on the northeast the Permian strata dip gently downwards without marked escarpments into the Salt basin. The northern half has a number of peaks of intrusive rocks, the most prominent of which are Cerro Alto at the northwest, the Cornudas Mountains farther east on the state line, the Sierra Tinaja Pinta to the south of the Cornudas, and Black Mountain (Sierra Prieta), which lies about halfway between Sierra Tinaja Pinta and the plateau's southeast corner. The southeastern corner of the plateau lies immediately north of the Van Horn uplift.

Structurally, the plateau is highest at the south in the Sierra Diablo, and next highest in the Hueco Mountains at the northwest. The broad sag between these two Paleozoic areas is covered by the Comanche Cretaceous.

The south scarp of the Sierra Diablo is in part at least a fault-line scarp. From the southeast corner near Van Horn this scarp gradually lowers westwards, and is no longer visible beyond Round Mountain, north of the town of Sierra Blanca. The faulting, which has uplifted the scarp with a displacement of at least 750 feet at the southeast corner, apparently diminishes westwards. At the southeast corner of the plateau the line or zone of faulting extends into Beach Mountain. The downthrow to the east is 1300 feet at the northeast corner of the Baylor Mountains. The base of the Permian rocks in the southern half of the eastern scarp of the Sierra

[21]Among publications relating to the Diablo Plateau and associated mountains cited in the bibliography of Vol. I are the following: Beede, 89 and 91; Darton and King, 396b; King, 936d; Richardson, 1304, 1312, 1313. and 1314.

Diablo lowers 2000 feet northwards in the 10-mile stretch between the southeast corner of the plateau and Victorio Peak. A fault at the base of the scarp is visible about a mile north of the mouth of Victorio Canyon, strata there being dragged down in an eastern block downthrown to the east.

The north-south scarp turns abruptly northwest at Apache Peak, and in the bend so formed a locally greater uplift exposes Montoya (Ordovician), Fusselman (Silurian), Percha (Devonian), and Pennsylvanian strata, unconformably overlain by the thick scarp-making Permian limestone. Beyond the bend, the northwest-trending scarp gradually lowers and passes into a low anticline 10 or 12 miles beyond the turn. This anticline is seen about 5 miles southeast of Black Mountain (Sierra Prieta). It has a very low-dipping southern limb. The north limb has dips of 15° and 20°. North of this anticline the strata of the plateau appear to have in general a gentle dip eastward from the Hueco Mountains, although intrusives, not all of which are yet exposed, have caused local doming, and there is some minor folding not connected with intrusives. In general the strata west of the prominent Sierra Diablo scarp dip very gently westwards.

The Finlay Mountains are a northwestward-elongated double dome, the two axes of which lie *en échelon*. The Leonard Permian is the oldest rock exposed, and the Trinity rimming the dome shows dips from 2° to 3° on the north and east and from 10° to 30° on the south and west. The dome is extensively penetrated by both acidic and basic intrusives, mostly in dikes and sills. Some minor doming and faulting are known to the east of the Finlay Mountains.

The exact nature of the structure of the Hueco Mountains is hard to determine because their west and southwest flanks are covered largely by alluvium of the Hueco Bolson. It is most probable that there is a broad anticline with northwest axis at the southeast but much lower in structure and striking northward farther north. The northern part is at least locally modified by the effects of igneous intrusions. The eastward and northeastward dips range from 5° to 15° and decrease to the east. On the opposite flank, west and southwest dips are known as high as 25° and 40° in the southern section but farther west on the flank are but 3°. The structurally highest area is in the southern end of the range, where all the earlier Paleozoic rocks are exposed.

There is no definite indication of any important fault at the west margin. Both in New Mexico and Texas small, low hills ("inselberge") are surrounded by alluvium. Strata in these hills more generally dip at low angles westward, but in some places are gently folded. Many of the exposures are covered by wind-blown sand. The physiographic evidence indicates that the residual hills belong to a westward-dipping cuesta, greatly eroded by prevalently consequent streams, and largely buried by encroaching alluvium swept down from the higher scarp slopes of the eastern cuesta. The higher part of the eastern slope is very greatly dissected by drainage lines largely adjusted to the strike and by broadly alluviated valleys which drain into the Hueco Bolson and not eastwards down the dip of the strata. The range is now being overwhelmed by its own débris.

Holocrystalline igneous rock outcrops in small hills in the alluvium south of the southern scarp, and a mile farther south there are some larger outliers of Silurian. The Permian rests with marked unconformity upon the older strata.

VAN HORN UPLIFT[22]

This uplift centers in the southern Carrizo Mountains in the southern border area of Culberson and Hudspeth counties. Its greatest amount of uplift occurs where the Carrizo Mountain formation outcrops, patches of that formation being visible also in the Wylie Mountains, in the eastern foot of Eagle Mountain, in the Mica Mine locality, and farther east in the northern Van Horn Mountains. The main area of the Carrizo Mountain formation lies between the Texas and Pacific and Southern Pacific railway lines.

Possibly the outlying areas of the Carrizo Mountain formation, except in the Van Horn Mountains, where it outcrops, are practically continuous under the areas of alluvium. At any rate, Chispa Creek from the south, and the Eagle Flat-Hot Wells-Dalberg drainage from the west apparently did not formerly enter Salt basin. The present underground water level at Hot Wells is more than 200 feet

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[22]Among publications relating to the Van Horn uplift cited in the bibliography of Vol. I are the following: Baker, 46 and 48; King, 936b; Richardson, 1314.

lower than at Lobo, and it is also 200 feet lower 4 miles north of Lobo than at Lobo. Apparently both Chispa Flats and the whole of the Eagle Flat-Hot Wells basin were formerly separated from Salt basin by bed rock divides, but these basins between the divides have filled up with alluvium to a level higher than the old basin divides.

The southwestern margin of the uplift forms the northwestern limit of the Mexican overthrust province. The southern edge of the Diablo Plateau is upthrown with reference to the country south by two faults trending south of east, the northern fault reversing its throw towards the east. A parallel fault farther south along the Texas and Pacific Railway line downthrows Permian and Cretaceous on the north against Carrizo Mountain on the south. The wedge-shaped downthrown block is bounded on the north by a fault zone trending south of west through Carrizo Spring. A fourth fault striking south of east with downthrow on south-southwest brings Permian in contact with Carrizo Mountain along the 31st Parallel north of Dalberg. A zigzag fault striking east of north with downthrow to the east brings Permian in contact with Ordovician near the east base of Beach Mountain. Baylor Mountains, with sub-horizontal Permian strata, are downthrown with respect to Beach Mountain on the south, with eastward-dipping strata, and to the Sierra Diablo on the west, with gently westward-dipping strata. On the north the Baylor Mountain rocks plunge under the Salt basin. The southeastern corner of the Diablo Plateau is upthrown about 750 feet stratigraphically above the Carrizo Mountains to the south and 1300 feet above the Baylor Mountains to the east. The southeasternmost point of the Diablo Plateau uplift is marked by a fault which extends east-southeast into Beach Mountain and which has its upthrow on the northwest. P. B. King recently has mapped other sub-parallel faults in the southeastern Sierra Diablo.

There is a strong probability that the series of downthrown blocks between the upthrown Diablo Plateau on the north and the upthrown block of Carrizo Mountain formation on the south were already in existence in pre-Ordovician time, although the faults were renewed after the Cretaceous. The faults of the block trend east-southeast, parallel, so far as known, with the strike of the Millican formation cut by the faults. Also, the basal Ordovician, or possibly earlier, sediments overlying directly both Carrizo Mountain and Millican show that both the latter formations, although of great difference in age, were then exposed. The fault along the Texas and Pacific Railway separates Carrizo Mountain from Millican, neither formation, so far as known, extending beyond the fault line, and Ordovician strata, present with considerable thickness on the north side, are absent south of the fault. The Millican dips southwards toward the older Carrizo Mountain, as if it would underlie were not the two separated by a fault which most probably has a very great displacement. Dr. P. B. King finds that farther west the Carrizo Mountain was overthrust northwards over the Millican, as was noted by Von Streeruwitz in 1889. The faults of the sunken block, although mapped as of the normal or gravity type, are at right angles to the other faults of the area, which will be described later. There is no evidence of the existence of these other faults before the last mountain-making epoch. It is perhaps significant that these presumably very ancient faults have strikes parallel with the line of Pennsylvanian folding in the Amarillo, Wichita, and Arbuckle mountains, and the Red River arch. Their line of strike, if continued, would pass beneath the Marathon basin approximately where the Variscan fold lines swing from nearly west to southwest.

A fault with maximum displacement of some 300 feet has upthrown the Carrizo Mountain formation against the Permian at the west foot of the Wylie Mountains. Near the point where this fault crosses the 31st Parallel, it is, for a short distance, a high angle thrust to the west, with the Permian overturned next the fault plane. The trace of the fault is gently arcuate with convexity to the west; most of its visible course is slightly east of south. The Permian strata in the uplifted fault scarp east of the displacement are gently arched, plunging more steeply northward at the 31st Parallel and more gently southward at the southern end of the range. The long eastward slope of the Wylie Mountains has in general an eastward dip, although in places the strata dip both east and west of north. In the north marginal area the strata dip northwards into the Salt basin. Low Permian hills to the west of the Wylie fault scarp have gently folded strata with strike parallel to the frontal fault.

In the part of the Carrizo Mountains around Bass Canyon (south of the 31st Parallel), the sedimentaries overlying the Carrizo Mountain dip at moderate angles to the southwest and are cut south of

Bass Canyon by two faults trending north-northwest with upthrow on the west-southwest, or down the dip of the strata. The fault crossing the 31st Parallel 2¼ miles north of Dalberg has its downthrow to the southwest, Permian limestone being dropped down to the level of the Carrizo Mountain.

The Carrizo Mountain formation also outcrops in the lower foothills of Eagle Mountain, west of and across the alluvial flat from Dalberg. In this region the formation is limited at the south by a fault running slightly south of west. This fault also cuts Permian and Trinity formations. The Carrizo Mountain is here exposed in a gently-dipping northwest-striking anticline, flanked in part at the west and northwest by the Permian.

The influence of the Van Horn uplift continues also into the northern part of the Van Horn Mountains, which are separated by an alluvial flat from the main Carrizo Mountain formation area to the northwest. The Carrizo Mountain of the Mica Mine locality, on the west flank of the Van Horn Mountains, is exposed in the heart of a north-northwest striking anticline and is flanked by the Permian. This anticline is bounded on the east by a north-northwest fault which drops the Lower Cretaceous of the eastern block. The Permian in the vicinity of Fay is gently folded along north-northwest strikes. An intrusive mass west of Van Horn wells has uplifted Carrizo Mountain, Van Horn, and Permian on its western and northeastern flanks. Quite possibly the southern part of the intrusion lies along a north-south fault at the eastern margin of the Van Horn Mountains. This fault is not certainly known, but the mountain front is notably straight and steep, and, what is more to the point, the strata in it dip southward at right angles to the range front, thus indicating that the frontal scarp has not been caused by erosion alone.

VAN HORN MOUNTAINS[23]

The Van Horn Mountains are a small range, skirted on the north by the Southern Pacific Railroad between Collado switch and Lobo station and extending south to the low gap of Chispa Summit, situated 5 miles west-southwest of Chispa section house. The structure of the northern end of the range has been discussed with the Van

[23]Among publications relating to the Van Horn Mountains cited in the bibliography of Vol. I are the following: Baker, 46 and 48

Horn uplift, of which it is the south flank. At least the southern third of the range is limited on the west by a fault. The evidence for the eastern front fault is given in the description of the Van Horn uplift. The western fault is the north-northwest end of the great Rim Rock fault zone. Earthquake cracks, showing recent movement, are found between the Taylor ranch house and the road to the Mica Mine at the head of Green River (Glenn Creek) valley, and the Rim Rock fault zone, if extended, would pass in the vicinity of these steep, straight, and narrow cracks.

There is a fault-bisected half-dome at the Mica Mine locality. South of it there is a low north-northwest-south-southeast anticline in Trinity strata, but in the east half of the range the Trinity dips rather uniformly southwards. This dip begins at the intrusive west of Van Horn Wells and continues, at the rate of about 4°, to the east-west cross fault which makes the wind-gap across the range 5 miles northwest of Chispa Summit. North of the wind-gap, in the vicinity of the summit ridge, there are four north-south faults of small displacement with variable directions of throw. To the west of them a narrow anticline and syncline are cut off to the north by another cross fault. The structure south of the wind gap fault is more complicated. To the west is an anticline and syncline with gentle dips, but the summit ridge of the range is an eastward-overthrust sheet which has a steep eastward-facing front. The overthrust plane is best exposed just south of the summit of the wind-gap. The block under the overthrust, which forms the eastern flank, has gentle west-southwest dips. The maximum overthrusting is found where the Fredericksburg Cretaceous rests on the Eagle Ford, the displacement there amounting to at least 500 feet. The present overthrust front extends in a sinuous course west-northwest-south-southeast. South of a small cross fault of the underthrust block, at the farthest northeastern projection of the overthrust sheet, dips in the underthrust block are southwards and vary irregularly from 2° to 10°. The overthrust sheet dips westwards at angles up to 30°. The overthrust ends in a southward-plunging asymmetrical anticline a short distance southeast of the Colquitt, or 66, ranch house. A fault, which in the part visible may be normal but is suspected of being a thrust, forms the northeast foot of the range between the wind-gap and Chispa Summit. This fault runs north-northwest. For the southeastern 3 miles of its course, its plane is occupied by a chalcedony vein carrying barite, hematite, and psilomelane. At Chispa Summit, or a short distance beyond, the fault passes into an asymmetrical anticline with a dip of 70° or greater on its northeast flank.

WYLIE AND CHISPA MOUNTAINS[24]

The Wylie Mountains are described under the Van Horn uplift, of which they form the eastern flank. The valley of Michigan Draw, between the Wylie and Apache mountains, is probably synclinal, connecting the structural depressions of the Salt basin and Big Bend.

Chispa Mountain and other low hills and mountains in its vicinity are built of volcanic and intrusive igneous rocks underlain in places by Trinity and other Cretaceous and Permian sedimentary rocks. The group is situated between the broad alluvial valley of Michigan Draw on the east and Chispa (Wildhorse) Creek on the west and between Valentine on the south and the Wylie Mountains on the north. It is herein regarded as the western outlier of the Davis Mountains.

TIERRA VIEJA MOUNTAINS (RIM ROCK COUNTRY)[25]

The Rim Rock country extends from Chispa Summit south for 50 miles to Pinto Canyon. The east flank is a simple eastward-sloping dip-slope, formed by the upper surface of a quartz-pantellerite sill or flow, which dips slightly east of north at 6° or 7°. This sill plunges underground along the strike at the Cienega ranch, beyond which the eastern cuesta of Capote Peak rises as an eastward-tilted fault block.[26] From Brite's ranch south, some diagonal faults cut the east flank. The structural summit of the range is made by the great Rim Rock fault, which has been traced for 55 miles without either end having been found. At the north this fault is single, although with a maximum displacement of perhaps 3000 feet or more, but in its central section it widens out into a broad zone of numerous parallel and sub-parallel faults. At its south end, from Silver Dome Mountain, 7 miles north of Pinto Canyon, to beyond Pinto Canyon, only a single fault is known.

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[24]Among publications relating to the Wylie and Chispa mountains cited in the bibliography of Vol. I are the following: Baker, 46 and 48; Keyes, 919a; Richardson, 1314.

[25]Among publications relating to the Tierra Vieja Mountains (Rim Rock country) cited in the bibliography of Vol. I are the following: Baker, 46 and 48.

[26]Personal communication from N. H. Darton.

The last movements were anticlinal in the central part of the range, with important faulting along the summit and western flanks. The remarkable feature of the fault blocks is that each is tilted east with upthrow on the east side of the fault. The same type of structure is found on the east flank of the Sierra del Carmen.

The structure is further complicated because the older Laramide folding produced uplifts which are greater in amount at places where the later uplift was less, and vice versa. Thus at the north end of the Rim Rock fault, the volcanics rest on the Trinity, the displacement on the fault there being not less than 1200 feet. At old San Carlos the volcanics rest on beds possibly as young as Fox Hills (Navarro) and perhaps as young as Laramie, the displacement in a single fault of the zone being a little over 3000 feet. And in Pinto Canyon the volcanics lie on the Word formation of the Permian, which is faulted against the upper Trinity, the displacement being perhaps 1000 feet or more. Complicating the structure still more, the western flanks of the central Tierra Vieja lie in the eastern edge of the Mexican overthrust province. The southern two-thirds of the range has as yet been only hurriedly studied, the area being less accessible than any other part of the state.

The main Rim Rock fault extends at least as far north as a point at the west base of the Van Horn Mountains situated 10 miles west of Chispa section house. Thence 2 miles south-southeast it marks the base of the mountains, the strata on the northeastern, or here upthrown, side dipping about S. 35° E. on the east flank of the anticline of the western Van Horn Mountains south of the east-west cross fault already noted in the description of those mountains. The fault runs at right angles to the strike of the Comanche and Eagle Ford strata to the northeast. In this two-mile stretch the Rio Grande basin deposits on the southwest reach to the fault, but 10 miles west of Chispa section house acidic volcanics of the southwestern downthrown block outcrop close to the fault, and a short distance farther south-southeast the fault-breccia zone is exposed at the west foot of the Comanche limestone scarp.

Beyond the 2-mile stretch and for the next 3 miles and probably farther, the fault becomes an eastward thrust with Cox sandstone of Trinity Cretaceous age thrust eastwards over Buda at the north and Eagle Ford of successively higher zones as one goes south. The

Cox sandstone of the overthrust block is overlain by a thick zone of large water-worn gravels and boulders of sedimentary rock with a tuffaceous matrix in turn overlain by rhyolitic lavas and tuffs of the Cenozoic volcanic series. Farther south-southeast and to the west of the 66 ranch house the volcanics of the overthrust block lie upon marls of Austin Cretaceous age in the overridden block. The thrust at its outcrop has a relatively high angle; at one locality, where the slickensided fault plane is visible, the plane of the fault dips westward at an angle of between 60° and 70°, though in some other places the dip is apparently less. The Eagle Ford flaggy and marly strata are overturned in the sole of the overthrust and dip westwards. Maximum displacement along the overthrust approximates 2000 feet.

Perhaps the greatest significance of this thrust is that it is clearly later than at least the lower part of the volcanic series, the older Laramide deformation being evident in the great time break between the Cox sandstone and volcanics in the overthrust sheet.

The throw reverses itself both to the north and south of the overthrust section and the fault scarp at the north end of the zone at the west base of the Van Horn Mountains is on the eastern or upthrown side of the fault but changes in the overthrust section to the western side of the fault, also the upthrown side. South-southeast, beyond the overthrust sector, higher strata of the volcanic series on the southwest side of the fault, here apparently downthrown, rest against Austin strata on the northeast and apparently upthrown side. The apparently downthrown side in this sector contains the scarp, the fault line scarp apparently being reversed or obsequent, explained probably by the volcanic series being much more resistant to erosive forces than the soft unconsolidated Austin marls of the apparently upthrown side. The broad valley of Van Horn Creek crosses the fault where the volcanics of the downthrown block are synclinal and moreover composed of very poorly resistant tuffs. Thence southwards to the Chinati Mountains—or as far as the Rim Rock fault zone has been traced—the downthrow along it is on the west side.

The reverse in the throw probably occurs only in the overthrust sector, where the fault is parallel with the overthrust 2 miles farther east already described in the account of the Van Horn Mountains.

On the back slopes of this eastern overthrust sheet in its central part are some remnantal masses of entirely angular blocks of Cox (Trinity) sandstone many of which have dimensions of 10 feet or greater. These rest on strata of upper Washita age. They are probably remnants of the former front of the western overthrust sheet.

These two overthrusts are in this latitude the easternmost of the thrusts of the Mexican overthrust province, the tectonics of which are well developed only a few miles to the west in the Mexican range of the Sierra de Pilares and its northwestward continuation across the Rio Grande in the Eagle Mountains and Devil Ridge of Texas. That the thrusting in the western of these two particular overthrusts belongs to the later Cenozoic epoch of diastrophism is demonstrated by the volcanic series being involved in it. It is likewise demonstrated by the physiography—the relative recency in age of the fault scarps on the upthrown sides of the displacements. In the eastern Mexican Cordillera of the overthrust province the folding and thrusting are so relatively recent that the mountains are still either anticlines or overthrust frontal scarps, a fact which probably demonstrates that their deformation is quite considerably later than Laramide.

The main fault in its northern single line, from 4 miles west of Chispa Summit to 1½ miles west of Vieja Pass, strikes generally parallel with the main faults to the north in the Van Horn and Wylie mountains and to the overthrust in the southeastern Eagle Mountains. That direction is north-northwest. But the fault trace is by no means straight, having four abrupt bends in the northern half with considerable drag and inclusion of upper Cretaceous rocks in the fault zone; the south half trends more northwest. In the southern 1½ miles of the section, nearest Vieja Pass, the fault branches, forming four parallel blocks which trend slightly west of north and dip west. The upthrow is on the west side of the blocks, although the main fault, which is here a "normal" fault, has its upthrow on the east. The Cretaceous strata of the upthrown side strike into the fault at an average angle of 45°, higher beds coming in on the east. Going southwards along the fault, beds from Washita to Taylor, or younger, successively form the eastern side. The Rim Rock scarp of the volcanic rocks forms the eastern scarp rim of the basin of upper Van Horn Creek, the creek occupying a broad basin in easily eroded Upper Cretaceous rocks. A mile south of Chispa Summit the volcanics rest on lower Eagle Ford (Benton) strata, which are, however, of upper Cenomanian age. Southwards the volcanics successively overlap higher strata of the Cretaceous, until west of Vieja Pass they rest on an upper sandy, clayey, and conglomeratic succession of nonmarine strata with abundant silicified wood. These strata are above the marine Taylor and also above the coal and dinosaur beds, and they may be as young as Laramie. The dip in the volcanics of the eastern cuesta increases from 2½° east at the north to 6° slightly north of east at Vieja Pass.

The opposite or western side of the north end of the fault is traversed by a syncline, at first paralleling the fault including its overthrust sector. Farther south, however, the fault has an irregular course nearly due south for 3½ miles, which brings the trough of the syncline at the south end of this stretch very near to the fault. Southwestward dips away from the fault generally vary from 30° to 60°, the Trinity sandstone (Cox) being thrust over the Eagle Ford at the north. Obsequent fault scarps, both north and south of Van Horn Creek, are found at intervals as far south as beyond Newman Springs, the southwestern, or downthrown, side forming the topographic highs. Evidently the quartz-pantellerite thinned out and disappeared to the west of the present rim, and the volcanics, being mainly ash beds, together with the underlying Upper Cretaceous marls, shales, and poorly consolidated sands and conglomerate, have rapidly eroded out of upper Van Horn Creek basin, thus giving a topography the reverse of the structure.

The volcanics overlie the Trinity in the syncline at the north end where the block is overthrust to the east, and farther south and extending beyond old San Carlos the volcanics are surface rocks of the downthrown block.

The middle and upper parts of the basin of Van Horn Creek have numerous dikes of olivine-basalt, later in age than the Rim Rock volcanics. These dikes strike in all directions, but the predominant strikes are southeast-northwest and north-south, only two being noted with strike of north of east and but three with strike approaching east-west. A number of the dikes inter-cross.

The main fault, south of a point west of Vieja Pass, turns more towards the south, continuing this general direction to the Chinati Mountains. The fault zone becomes complicated in the section centering around the old San Carlos coal prospects where it is 6 miles in breadth. The fault of greatest displacement—more than 3000 feet—is a sub-zone of two parallel faults a short distance apart, which forms the west side of the San Carlos dome now eroded into a topographic basin. The greatest displacement comes about a mile south of Brocks Canyon. This fault has downthrow to the west with a synclinal sag in the sunken block near the point of greatest displacement. The uppermost Cretaceous of the San Carlos domical basin is cut by 18 known faults and one nearly north-south basalt dike. There is also one small overthrust. The faults, some of which cross or join, strike both east and west of north. The volcanics west of San Carlos basin are cut into blocks, tilted in various directions, by at least three major faults, which strike slightly east of north, and four minor faults, three of which strike west of north and one east of north. Lower Van Horn Creek follows a broad, fairly gentle, northeast-striking syncline to the west of the faults.

There is a large area of Upper Cretaceous south and southwest of San Carlos which has not been sufficiently studied for a complete report, but it is known to be broken up into a number of fault-blocks. In these the general dip is westward and at places, especially towards the west, at high angles; hence, there is likely some repetition of strata and quite possibly some overthrusting. In some of the downthrown blocks the volcanics are dropped against the Cretaceous.

Perhaps the most remarkable fault phenomenon is exhibited in an area 12 miles in length and 4 miles in width just south of the San Carlos basin, in which only the main and easily visible faults have been mapped. There are at least five long, narrow, main blocks, each upfaulted on the east side and each tilted eastwards at a moderate angle. The general structure lowers to the west in a series of inclined steps which dip toward, and not away from, the highest structures. Three minor faults, perhaps caused by the slumping of the steep slopes of the main Rim Rock scarp, occur east of the main zone. The greatest downfaulting of the quartz-pantellerite in the series of steep faults is at least 1300 feet. The fault zone is bounded on the west by an anticline, which passes through Alamo Tank and in which very high Cretaceous is exposed. The faulting gradually lowers the rocks to the south-southeast.

Only a single fault is yet known between the old Knight ranch on Walker Creek and the Capote ranch. In this section a relatively narrow strip of Austin, Taylor, and perhaps later Cretaceous, is upthrown on the east against volcanics on the west. The structure in the somewhat folded volcanics west of the fault is not known, but a broad southeastward-plunging anticline crosses lower Capote Creek.

The main fault sends off a number of branches to the east in the section between Capote ranch and Silver Dome Mountain. These branches vary in strike from north-south to north-northeast. One of the faults extends from near Cienega ranch north-northeast to the vicinity of Brite's ranch, and bounds the upthrown block of Capote Peak, which is tilted 8° east. The others make three prominent scarps east of Mexican Spring; the middle block is down-dropped.

The Edwards limestone of the upfaulted block dips up to 14° north in Silver Dome Mountain, where limestone-replacement silver-lead deposits of the Shafter type occur. Silver Dome Mountain is the north end of a north-south anticline in which the downcutting of Pinto Canyon has exposed Word Permian of the Chinati facies. The highest Cretaceous visible in this anticline is the Georgetown of the east flank. Both Cretaceous and Permian are directly overlain by volcanics. Where the fault passes into the western lower flank of the Chinati Mountains in the south wall of Pinto Canyon, upper Trinity is downfaulted against the Word Permian lying to the east.

The course of the Rio Grande west of the Rim Rock follows fairly closely the eastern edge of the Mexican overthrust province. The eastern dipping cuesta of the Rim Rock dips gently towards the Big Bend depression.

The Rim Rock eastern cuesta is bounded near its southern end by the broad, smooth-contoured valley of Capote Draw, east of which is a prominent westward-facing scarp of volcanic ash capped by lava. The scarp gradually lowers to the north, ending in the flat west of Ryan and south of Valentine. It extends south in nearly a straight line for 10 miles and then gradually swings to the south-east in the greatly eroded Cuesta del Burro, the swing occurring where the dip in the volcanic rocks turns from east to northeast. The Cuesta del Burro itself shows a northeastward plunge off the Chinati uplift, and its scarp side is greatly dissected by the steep-gradient drainage of the Rio Grande. The turn in the scarp, however, comes in the interior drainage of upper Capote Draw. The scarp front, most prominent north of the divide between the Rio Grande and Salt basin, may possibly be explained as the eroded margin of lava flows from the Chinati eruptive center, or it may prove to be at least in part caused by faulting.

The Rim Rock uplift was formed by the later Cenozoic deformation and connects Laramide uplifts of the Van Horn region at the north with the Chinati Mountains at the south. The amount of the Rim Rock uplift is greatest in the faulted dome of the San Carlos area, which the Laramide uplift affected little or not at all; at least, the area from Vieja Pass to the Capote ranch was synclinal at the end of the Laramide epoch.

CHINATI, CIENEGA, AND BOFECILLOS MOUNTAINS[27]

The Chinati Mountains are the south-southeast end of the belt of uplift which extends 100 miles from west of Van Horn to south of Shafter. The Chinatis are that part of the belt situated south of the transverse valley of Pinto Canyon. This canyon crosses an anticline of Word (Delaware Mountain) Permian rocks flanked to the east by Comanche Cretaceous and on the west by the main Rim Rock fault, on which the Trinity is faulted down against the Permian. Along a line which is approximately the south wall of Pinto Canyon the axial lines of the uplift bend from nearly north-south at the north to N. 33° W. at the south. This line is also approximately the north border of an intrusive, measuring more than 7 miles from north to south and more than 6 miles from east to west, which forms the high ridge of the northwestern Chinati Mountains and occupies the broad basin of San Antonio Canyon to the east. East of the latter is Chinati Peak, the highest summit of the range, which is composed of volcanic rocks, about 3000 feet thick, tilted gently eastwards by the intrusive to the west. To the south and east of Chinati Peak is a high dissected plateau of volcanic rocks, the southeast end of which extends to within 2½ miles northwest of the town of Shafter. On

[27]Among publications relating to the Chinati, Cienega, and Bofecillos mountains cited in the bibliography of Vol. I are the following: Baker, 46 and 53; Udden, 1623.

the east and south the volcanic plateau is flanked by outwardly dipping Permian and Cretaceous sedimentary rocks, dipping east on the east margin and swinging around in the vicinity of Shafter to a south dip on the south margin. At the southwesternmost margin the Cretaceous rocks dip southwestwards off a small porphyry intrusion. The north flank of the uplift is visible along the 30th Parallel, the northward dip continuing northwards to the Capote ranch in the Rim Rock country (Tierra Vieja Mountains).

The greatest amount of uplift, more than 7500 feet, so far as known, is on the northeast flank, on the east side of the Ojo Bonito intrusive porphyry,* from about 3 to about 6 miles south of the 30th Parallel. Here are exposed Permian strata of an approximate thickness of 7500 feet to which is to be added a considerable but difficultly computable thickness of Cretaceous and volcanic rocks in order to arrive at the total amount of uplift. There is considerable probability that the intrusive masses in Pinto Canyon on the north, of Ojo Bonito on the east, and the large exposure of San Antonio Canyon and the broad ridge to the west are more or less continuous underneath the intervening volcanic plateau.

There are possibly four epochs of deformation exhibited in the exposed rocks of the Chinati Mountains as follows: (1) Post-Permian and pre-Cretaceous. Although no noticeable angular unconformity occurs between Cretaceous and Permian rocks, pre-Cretaceous erosion removed about 1000 feet more of the Permian on the north flanks than on the south and southeast flanks. (2) Laramide. The Permian and Cretaceous rocks were gently domed and greatly eroded before the outflow of the angularly unconformable overlying volcanic rocks. (3) A large amount of tilting and doming of the volcanic and older rocks by intrusive forces. (4) Late Cenozoic faulting of large displacement, with tilting of all the consolidated bed rocks. So far as known, the faulting (which displaces the intrusives) occurred during the fourth and final diastrophic epoch. The largest visible intrusive mass of the northwestern part of the mountains occupies the Rim Rock fault zone, the central part of the intrusive being in the probable continuation of the fault between its two known portions.

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*The scale of the map on page 75, "Note on the Permian-Chinati series of west Texas," by C. L. Baker, Univ. Texas Bull. 2901, 1929, is 1 inch to the mile instead of 2 inches to the mile as there stated.

The igneous history of the range is complex. Most of the volcanic flows, tuffs, and tuff-breccias appear to be rhyolitic. The larger intrusive masses, which cut the rhyolitics and are therefore at least in part later than the rhyolites, are acidic to intermediate, ranging from felsite through granodiorite or quartz-monzonite to syenite and diorite. In the large northwestern intrusive mass an older altered syenitic rock is intruded by numerous bodies of quartz-monzonite or granodiorite porphyry, the largest of which comprises the high mountain area west of San Antonio Canyon. Still later are dikes and sills of hornblende-diorites and olivine-diabases (dolerites).

The faulting is complex and mostly unknown. There are known, however, to be two dominant systems of faulting, one, or the Rim Rock system, striking about N. 33° W., and the other, varying in strike from east-west, to N. 75°–80° E. to about N. 70°–80° W. The structure, so far as known, is shown in the accompanying map (fig. 16), based on field explorations by Dr. J. A. Udden and the writer. The exposed sedimentary rocks, more continuously exposed on the east, southeast, and south flanks, but visible also on the northwest and southwest margins, indicate a general domical uplift about 15 miles wide and about 30 miles long in a northwest-southeast direction. The southwest boundary fault, the main continuation of the Rim Rock fault zone, is apparently traceable from the exposed edge of the porphyry 2 miles southeast of the mouth of San Antonio Canyon S. 33° E. for a distance of about 8 miles, to where it passes beneath the alluvium. It separates bed rock exposures to the northeast from alluvial deposits to the southwest. Its northwestern half forms the straight line base of the southwest-facing scarp of the volcanic plateau. Farther southeast it forms the limit of Trinity Cretaceous rocks dipping about 12° southwest. The downthrow is in the southwest block, towards the Rio Grande. There are four parallel faults within the area 3¼ miles broad next northeast of the southeast visible part of the main boundary fault. The two western fault blocks contain intrusives; the Permian rocks are offset along the faults. Probably there are some minor faults within the area a mile northeast of the above mentioned, which are marked by southeastward offsets in Permian strata.

Another fault of this system, striking N. 25° W., on the northeastern flank of the range, extends north-northwest from the northwest corner of the Ojo Bonito intrusive porphyry. This parallels the strike of the Permian rocks from east of the Ojo Bonito porphyry to east of the Cieneguita ranch house.

Another probable fault of this system, this one striking about N. 37° W., marks the straight base of the northeastward-facing scarp of the lava plateau from a point 3 miles northwest of Shafter northwestward to at least 2 miles northwest of Poole's ranch house. The upper half of Oso Creek valley follows mainly the course of this suggested fault. In direct continuation with it to the southeast is the southeast-plunging half dome in the Permian and Cretaceous

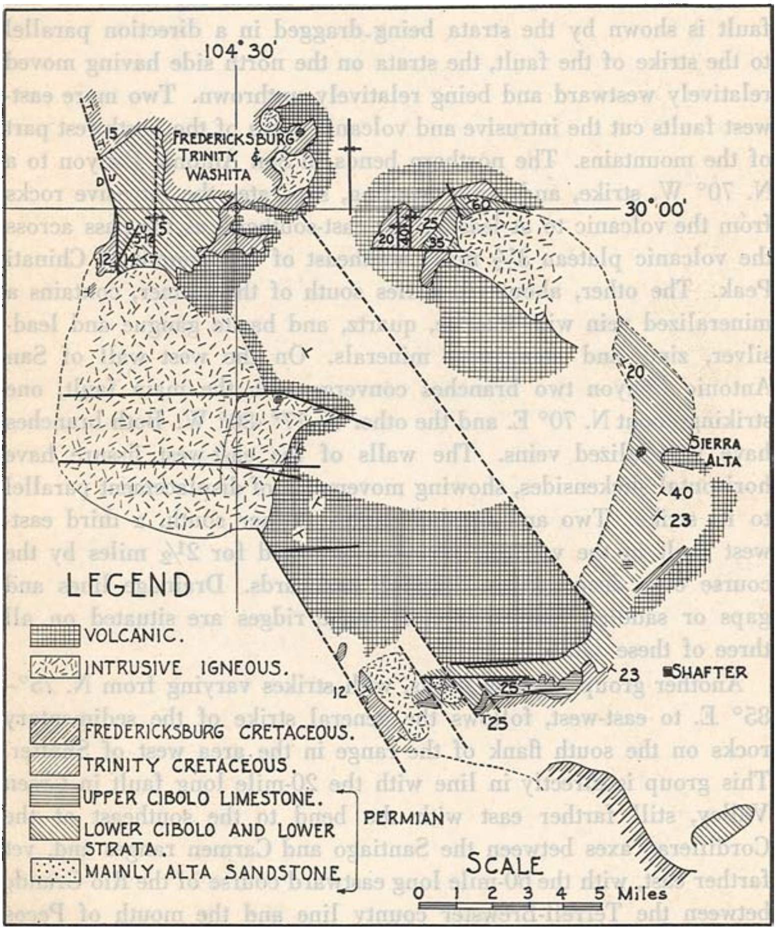

Fig. 16. Exploratory geologic map of the Chinati Mountains.

rocks forming the southeast corner of the Chinati uplift. West of the axis the strata strike westwards and to the north of it northwards. Possibly the Morita dome, exposing the Lower Permian, 6 miles south-southeast of Shafter, is on or near the axial plunge, the exact situation of the dome being unknown to the writer.

The known faults of the east-west system will now be noted. The northernmost, which strikes about N. 85° W., is on the northwest side of the Ojo Bonito porphyry and displaces Permian, Cretaceous, and volcanic rocks, the displacement at the edge of the porphyry being 1850 feet or greater. Horizontal, lateral movement on this fault is shown by the strata being dragged in a direction parallel to the strike of the fault, the strata on the north side having moved relatively westward and being relatively upthrown. Two more east-west faults cut the intrusive and volcanic rocks of the northwest part of the mountains. The northern bends in San Antonio Canyon to a N. 70° W. strike, and, upon bending, separates the intrusive rocks from the volcanic to at least as far east-southeast as the pass across the volcanic plateau 3½ miles southeast of the summit of Chinati Peak. The other, about 1¾ miles south of the former, contains a mineralized vein with fluorite, quartz, and barite gangue and lead-silver, zinc, and manganese minerals. On the west wall of San Antonio Canyon two branches converge with the main fault, one striking about N. 70° E. and the other N. 77°–80° W. Both branches have mineralized veins. The walls of the east-west fissure have horizontal slickensides, showing movements of displacement parallel to its strike. Two and one-half miles farther south, a third east-west fault in the volcanic series is followed for 2½ miles by the course of a deep canyon draining westwards. Drainage lines and gaps or saddles between inter-drainage ridges are situated on all three of these faults.

Another group of these faults, with strikes varying from N. 75°–85° E. to east-west, follows the general strike of the sedimentary rocks on the south flank of the range in the area west of Shafter. This group is directly in line with the 20-mile long fault in Green Valley, still farther east with the bend to the southeast of the Cordilleran axes between the Santiago and Carmen ranges and, yet farther east, with the 60-mile long eastward course of the Rio Grande between the Terrell-Brewster county line and the mouth of Pecos River. Five faults in this belt occur in an area only a mile wide.

The southern one, striking N. 80° E. and dipping 37° to the north-northwest, contains the galena vein of the old Chinati mine workings. The next two to the north have between them a narrow block of heavy Cibolo (Upper Permian) limestone downthrown at least 1000 feet, the northern one containing the vein and wall rock replacements of the old Humphries-Ross mine workings. The block to the north of the latter is still more downthrown, consisting of volcanic tuff-breccia. North of the last is a narrow upthrown block

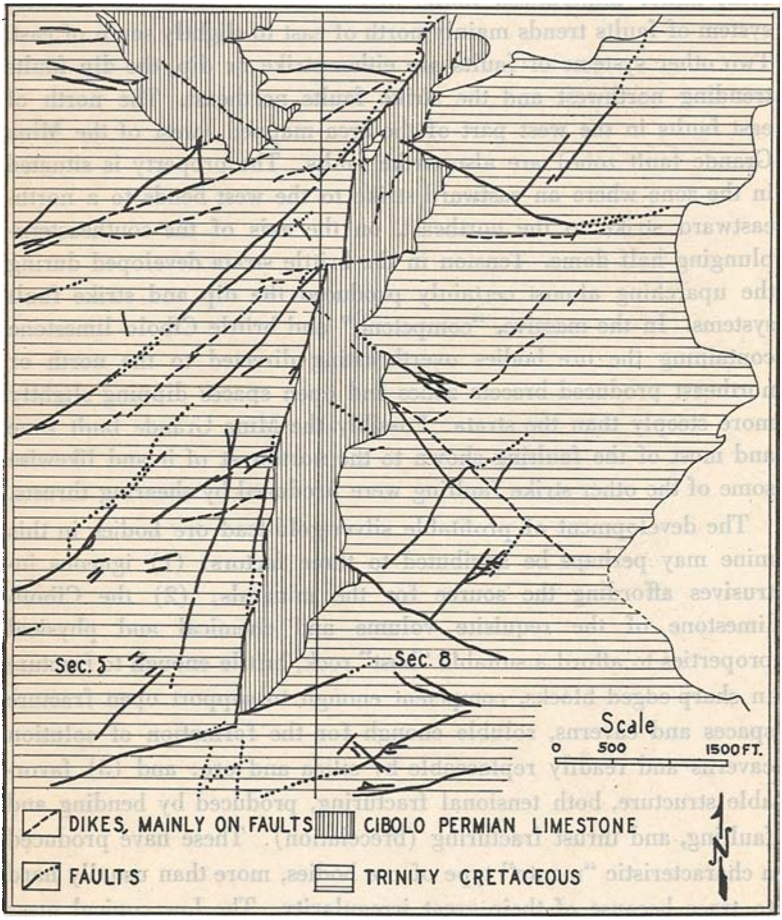

Fig. 17. Map showing surface faults and dikes on a part of the Presidio mine property, Shafter district, Chinati Mountains. Contributed by A. W. Frolli.

of heavy Cibolo limestone, bordered to the north by another mineralized fault, along which volcanic tuff is downthrown.

A detail map of the surface faulting on a part of the Presidio mine property of the American Metals Company, made by A. W. Frolli, is given in Figure 17. Faulting here is both pre-mineral and post-mineral. At least some of the intrusive dikes are also post-mineral. One of the most important post-mineral fault zones is the Mina Grande, which strikes N. 15° E., more or less parallel with some minor mineralized faults to the west of the mine. Another system of faults trends mainly north of east to slightly south of east. Two other systems of faults are either strike or dip, the dip faults trending northwest and the strike faults northeast. The north of east faults in the west part of the area mapped (west of the Mina Grande fault zone) are also strike faults. The property is situated in the zone where an eastward strike to the west bends to a northeastward strike to the northeast, on the axis of the southeastern-plunging half dome. Tension in the brittle strata developed during the uparching almost certainly produced the dip and strike fault systems. In the massive, "competent," and brittle Cibolo limestone containing the ore bodies overthrusting directed to the north or northeast produced breccia zones and open spaces dipping slightly more steeply than the strata. Possibly the Mina Grande fault zone and most of the faulting shown to the northwest of it and likewise some of the other strike faulting were produced by shearing thrusts.

The development of profitable silver-gold-lead ore bodies in this mine may perhaps be attributed to three factors: (1) igneous intrusives affording the source for the minerals; (2) the Cibolo limestone of the requisite volume and chemical and physical properties to afford a suitable "host" rock, brittle enough to fracture in sharp-edged blocks, competent enough to support open fracture spaces and caverns, soluble enough for the formation of solution caverns and readily replaceable by silica and ore; and (3) favorable structure, both tensional fracturing, produced by bending and faulting, and thrust fracturing (brecciation). These have produced a characteristic "manto" type of ore bodies, more than usually hard to trace because of their great irregularity. The low conical mass of the Cienega Mountains, 9 miles east-southeast of Shafter, is a laccolitic intrusion.

The Bofecillos Mountains are situated in southern Presidio County west of Fresno Canyon and southeast of Alamito Creek. The Rio Grande crosses them in gorges and canyons. So far as known they are composed of volcanic lavas and tuffs. Some of the flows are reported by M. B. Arick to be interbedded with the Rio Grande basin deposits.

MEXICAN OVERTHRUST PROVINCE OF THE MALONE, QUITMAN, AND EAGLE MOUNTAINS[28]

The Mexican overthrust province enters Texas in southeastern Hudspeth County. Its northern boundary extends from Alarcon Hill, 7 miles northwest of Finlay, eastward to just north of the Sierra Blanca Peaks, thence east-southeastward to the head of Green River (Glenn Creek), thence southeastward to 7 miles west of Chispa section house, and thence southward to the Rio Grande near the mouth of Van Horn Creek. In this province the Cretaceous rocks have been more highly deformed than in any other part of Texas.

The date of the intense deformation in the Malone, Quitman, and Eagle mountains cannot be stated with certainty. The volcanic rocks which overlie the bevelled folds of Cretaceous are rhyolites and trachytes like the older volcanic rocks of the Big Bend region and Davis Mountains. However, it is possible that they are younger. The volcanics are cut by a later normal fault in the northeast flank of Eagle Mountain. The strongly folded and overthrust Cretaceous strata are cut by later large intrusions in the northern Quitman Mountains, but many intrusions in Trans-Pecos Texas are later than the older volcanics. Sierra Blanca and Eagle Mountains have the appearance of being local volcanic centers.

The north-northeast limit of the northeastward overthrusting as far east as the Van Horn uplift comes in a zone along which the Cretaceous sediments greatly thin towards the north. The close folding and thrusting occur in the site of a former geosyncline, in which a thickness of some 10,000 feet of Cretaceous was deposited.

The main or northeastern ridge of the Malone Mountains is a syncline overturned on the southwest flank. The northeast limit of this syncline is overthrust along a plane of lubrication in the Permian

[28]Among publications relating to the Mexican overthrust province of the Malone, Quitman, and Eagle Mountains cited in the bibliography of Vol. I are the following: Baker, 46 and 55.

gypsum. A great amount of shortening of strata has taken place along the gypsum horizon, although, on the overthrust sheet, younger strata of Upper Jurassic and pre-Trinity Cretaceous rest on the Permian.[29] South of the frontal overturned syncline are a narrow, closely compressed anticline and syncline, flanked on the southwest by an anticline overturned to the northeast. The general strike of the folds is northwest-southeast.

A zone of overthrusting, much concealed by alluvium, extends between the granitic intrusive of the northern Quitman Mountains and the north side of the lava-capped Sierra Blanca peaks. There are either two overthrusts or a single, later-folded overthrust. Sierra Blanca peaks are underlain by bevelled isoclinal Del Rio and Georgetown, stripped off the sole under the thrust plane and piled in folds ahead of it. Permian strata rest on Del Rio, with a stratigraphic displacement of about 5000 feet at a locality south of the main Sierra Blanca peak. A short distance north of the old highway and about a mile east of Lasca, metamorphic schistose quartzite, either basement complex or metamorphosed later sediments, is exposed in the overthrust sheet. The overthrusts end abruptly before reaching the ridge of low westward-dipping Trinity just north of the town of Sierra Blanca. Intrusives are numerous in the overthrust zone.

There is one overthrust in the southern Quitman Mountains, two in Devil Ridge, and one in the southern Eagle Mountains. These may be merely extensions of the overthrusts in the Malone Mountains and the Sierra Blanca area as alluvium conceals the intervening area. Two overthrusts are found in the southern Van Horn Mountains west of Chispa Summit. Most of the strata in the southern Quitman Mountains, the Devil Ridge and adjoining territory, and on every side of Eagle Mountain are isoclinal in structure and dip southwest. The strike abruptly turns to the northeast-southwest 5 or 6 miles south of the summit of Eagle Mountain, and to the south

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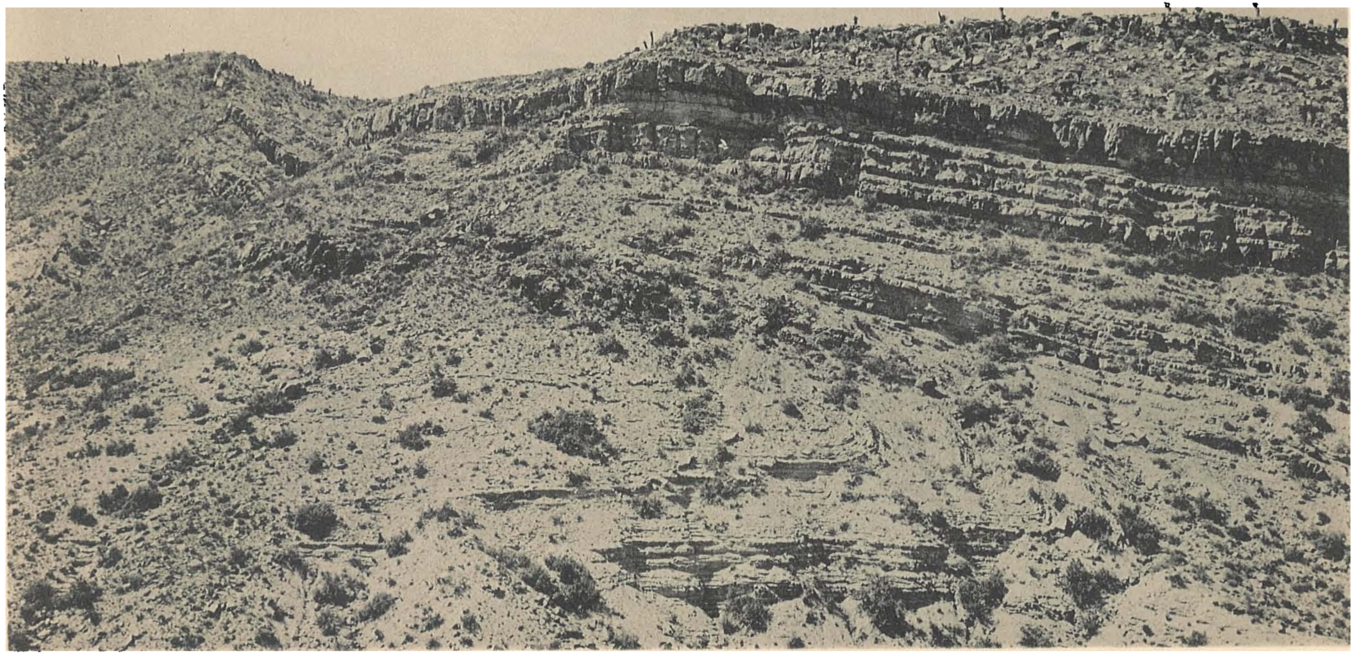
[29]A possible alternative, favored by the occurrence of extensive gypsum in the Trinity Cretaceous of the lower Rio Conchos Valley in Chihuahua west of Presidio, Texas, by normally marine fossiliferous limestone beds of Leonard Permian age occurring without transition deposits in the gypsum of the Malone Mountains, and by the fairly strong probability that the Permian of the Malone area should be normally marine and without saline residues, is that the Malone gypsum is Trinity in age, overlain by overthrust Permian, Upper Jurassic, and Lower Cretaceous. The fossiliferous Permian limestone may have been infolded with a younger gypsum. The writer has seen normally marine fossiliferous Upper Jurassic limestone infolded with great complexity in gypsum in areas of thrusting in the mountains of northeastern Mexico.



Eastward overthrust of Trinity (to right) over Fredericksburg and Washita Cretaceous (to left). West wall of wind-gap canyon along an east-west cross fault, 9 miles west-northwest of Chispa section house. Locality is near the southwest corner of Culberson County.

the strata are, in the main, normally folded with north-northwest strike, except to the east of Oxford Mountain where there is some overfolding and Trinity is overthrust over Taylor. Strikes in general turn more nearly south as they approach the Rio Grande.

The high mesa south of the railroad, about midway between Sierra Blanca and Etholen, has a north-northwest normal fault west of a south-plunging syncline, with a maximum downward displacement to the west of over 1000 feet. The east face of the ridge, 4 miles north of the town of Sierra Blanca, has three small normal faults with strike west of north with downthrow to the east. Another normal fault with north-northwest strike, in the northeast flank of Eagle Mountain, downthrows the volcanics on the west against Trinity on the east. The other normal faults in this area strike slightly south of west. They are characterized by large horizontal displacement. One is found in the southern Quitmans just west of the divide on the Hot Springs road, and three are found in the northern Eagle Mountains. The one through Eagle Springs has a horizontal displacement of almost a mile and the one farther north in the northwest flank of Eagle Mountain of approximately 2000 feet. The Eagle Mountains and Devil Ridge are the northwestern part of the Sierra de Pilares of Mexico, the latter range forming the western boundary of the Rio Grande Valley, facing the Rim Rock country.

HUECO BOLSON[30]

The Hueco Bolson is an intermontane basin in part downwarped and in part downfaulted, which extends from the center of New Mexico southwards to the latitude of El Paso and then extends southeastwards until it finally leaves Texas at the place where the Rio Grande cuts across the Quitman Mountains. It crosses the river, but how far it extends into Mexico is not known. It has a length in the United States of 250 miles. Its northern part, the Tularosa or Otero basin of New Mexico, is still undrained, but the part which lies in Texas is now drained by the Rio Grande. Its eastern and northeastern boundary in Texas probably is formed by a line of monoclinal downwarps, with dips towards the basin from the Hueco

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[30]Among publications relating to the Hueco bolson cited in the bibliography of Vol. I are the following: Baker, 46 and 48; Darton, 395; Richardson, 1304 and 1312.

Mountains, the Diablo Plateau, and the Finlay and Quitman mountains. Its western limits in Texas are the upfaulted westward-tilted blocks of the narrow range of the Franklin mountains.

The Cinco Minas boring in the Hueco Bolson near the Texas-New Mexico line was still in the basin deposits at a depth of 4920 feet. North of Fort Bliss, near El Paso, water wells have penetrated 2300 feet of these deposits without reaching their base. The Layne Texas Company No. 1 Silix Malone boring near Tornillo, in the Rio Grande Valley southeast of El Paso, was drilled to a depth of 3064 feet and failed to reach the underlying bed rock.

FRANKLIN MOUNTAINS[31]

The Franklin Mountain range is the most individualized range of Trans-Pecos Texas. Its appearance from almost any direction, and especially from the town of El Paso to the south and from the Hueco Bolson to the east, must arrest the attention of any observer. Although the range is a unit, the general line of north-south structure is continued northward into the Organ and San Andres mountains of New Mexico. The rocks in the Franklin Mountains dip westwards and form eight major and several minor fault-blocks. Faults bounding the blocks are in large part north-south and parallel to the range trend, but two of the longitudinal faults bend until they take diagonal directions, and two of the faults are entirely diagonal.

The range, long and narrow, rises 3000 feet above lowlands and resembles a "basin range" fault block of westward-dipping rocks. Erosion has progressed so far that a frontal fault, if existent, is no longer visible but lies buried beneath the waste products of the piedmont.

All the rocks are prominently jointed in two close, almost vertical sets, one parallel to the range trend and the other at right angles and transverse to it. The Anthony downfaulted block forms the west base, and the suggestion is that the upthrust range has been rotated by compressive forces and broken by them into various blocks. By such rotatory tilting, the space originally occupied by the rocks would be narrowed in width east-west, the blocks being

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[31]Among publications relating to the Franklin Mountains cited in the bibliography of Vol. I are the following: Darton, 396; Darton and King, 396b; Richardson, 1304, 1309, and 1312; Van Hise and Leith, 1682a.

squeezed upwards and tilted during the process. The normal type of faulting would most likely be produced if the blocks at the time of deformation were not covered by any great superadjacent load. The rocks being brittle (or structurally "competent") would yield by fracturing rather than bending. It is apparent also that some of the fractures were conduits through which large masses of granite were intruded.

The greatest displacement on the western or back-bounding fault, amounting to more than 2500 feet, is in the central part of the range. The central block of the mountains is the highest unit structurally, and the simplest, and is known as Mount Franklin. Although its east flank is composed of intrusive rock, the only longitudinal faults which affect it are the two close together at the western foot. Blocks both to north and south are downfaulted along cross-fractures; to the north of the northern cross-fracture the east flank of the range has been downfaulted more than 3000 feet along a north-south displacement, and along the fault on its downthrow side a great mass of granite has been intruded which crosses the range on the south side of the northern cross fault and also forms most of the eastern flank of the central block.

South of the central and highest block, the main longitudinal fault extends along the eastern flank of the ridge north of El Paso and turns northeast into a cross fault down Fusselman Canyon. At the southern end, granite borders the dislocation. The eastward downthrow of the fault amounts to about 2300 feet at a maximum. East of Mount Franklin the eastern downthrown block splits into two, with a fault of 700 feet displacement down McKilligan Canyon. Another fault, with eastward downthrow of more than 1000 feet, is found at the easternmost base of the outlying ridge north of Fort Bliss. Intrusive granite forms most of the eastern base of the Mount Franklin Ridge south of McKilligan Canyon. The western longitudinal block of the Franklin Range is structurally the highest, the flanking blocks being downthrown.

It is probable, from the intimate relationship between granite intrusion and faulting, that intrusion, faulting, and range uplift were all closely connected in time. The northern end of the Franklin Range gradually ends in lower structure north of the state line, but the southern end is abruptly cut off, probably by diagonal fracturing. It chances, as long ago pointed out by R. T. Hill,[32] that the south end of the range comes along a zone of important faulting which is an extension of the north-northeast limit of the Mexican overthrust province farther southeast, and that the zone, if extended northwestward, would form the limit between the more gently deformed plateau province on the north and the more complicated basin and range structure on the southwest. The line referred to has the direction of the pre-Ordovician fault and strike lines of the Van Horn uplift. Hill's view of its being a major continental structural line is quite plausible.[33]

STRUCTURAL INFLUENCES OF APPROXIMATELY EAST-WEST TREND

There are two belts or zones in Trans-Pecos Texas in which cross structures interrupt and influence the more general strikes of the Cordilleran orogeny. These are a part of more widespread cross structures of the Western Hemisphere considered elsewhere.[34] The cross belts in Trans-Pecos Texas are the following:

(1). A zone which at the east is near the 31st Parallel and turns beyond Van Horn to the northwest and extends to El Paso.

(2). A zone at 29° 45′ North Latitude which extends from the mouth of Pecos River westward to the south end of the Chinati Mountains near Shafter.

(1) The first zone referred to is perhaps most evident between the 104th and 105th Meridians, where it runs practically east-west. The belt traversed by the Texas and Pacific Railway between Kent and Plateau has a gentle southward dip from the Delaware-Apache uplift, giving that uplift a very blunt south end. Farther west, south of the railway, the Permian limestones of the northern visible flank of the Wylie Mountains plunge northwards under the Salt basin. The railway between Van Horn and Allamoore follows a fault already in existence before the Ordovician but with renewed displacement which has downthrown the Cretaceous. Just north of Eagle

[32]Hill, R. T., The geographic and geologic features, and their relation to the mineral products of Mexico: Trans. Amer. Inst. Min. Eng., vol. 32, pp. 163-178, 1902.

[33]See also, F. L. Ransome in Problems of American Geology, Yale University Press, New Haven, pp. 287-376, 1915.

[34]Baker, C. L., Rotational stress as possible cause of fundamental crustal deformation: Pan-American Geol., vol. 59, pp. 19-32, 1933.

Flat railroad station the Carrizo Mountain metamorphics are thrust northwards over the Millican. Thence west-northwestward through the valley in which the town of Sierra Blanca is situated to underneath the Sierra Blanca peaks the cross-zone marks the north-northeast limit of the Mexican overthrust province. Farther west the zone passes beneath the alluvium-covered area between the south flank of the Finlay Mountains and the northern overthrust base of the Malone Mountains. It there becomes concealed by the detritus of the Hueco Bolson, but the abrupt termination of the Franklin Mountains at El Paso indicates a transverse fault with downthrow to the south, first noted by R. T. Hill and later by Richardson.[35]

The fault zone at the south-southeast corner of the Diablo Plateau, parallel with the fault along the railway between Eagle Flat and Van Horn, and the Seven Heart Gap fault zone, extending from the Salt basin to beyond the railway, which it crosses between Kent and San Martine, come within the influence of the transverse belt. Its northern limit extends eastwards from the east-west fault limiting the Hueco Mountains on the south through the eastward-plunging broad syncline of the consequent basin of Brackett Draw.

East of the 104th Meridian the cross zone is not so prominent but appears to have localized an east-west line of springs, including Phantom Lake and San Solomon Springs at Toyahvale; Comanche and Leon Springs, at and near Fort Stockton; and to the east of this town the three Escondido Springs and Tunas Springs. Farther east, near Pecos River, the east-west striking southern flank of the Yates oil field would appear to be along the transverse belt.

This zone was first noted by R. T. Hill[36] and later discussed briefly by Ransome,[37] who suggested that it be called the Texas Lineament. Some idea of the great influence of this transverse zone is given by the following table, which contrasts the territory to the north and the south of it.

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[35]Richardson, G. B., Description of the El Paso district: U. S. Geol. Surv., Geol. Atlas, El Paso folio (No. 166), 11 pp., 1909.

[36]Hill, R. T., The geographic and geologic features, and their relation to the mineral products of Mexico: Trans. Amer. Inst. Min. Eng., vol. 32, pp. 163–178, 1902; Data on the geographic nomenclature of the southern California and Texas regions (abst.): Bull. Geol. Soc. Amer., vol. 34, p. 67, 1923; and The transcontinental structural digression (abst.): Bull. Geol. Soc. Amer., vol. 39, p. 265, 1928.

[37]Ransome, F. L., Tertiary orogeny of the North American Cordillera and its problems: *in* Problems of American Geology, Yale University Press, New Haven, pp. 295, 358, and 369, 1915.

Southern	*Northern*
1. No basement complex certainly exposed.	Basement complex exposed in four ranges.
2. Thick geosyncline facies of pre-Permian Paleozoic.	Thin foreland facies of pre-Permian Paleozoic.
3. Shore line Permian facies.	No shore line Permian facies.
4. Full section of thick geosynclinal Cretaceous.	Thin shore line Middle Cretaceous; no Upper Cretaceous.
5. Intrusions abundant.	Intrusions rare.
6. Volcanics abundant.	Volcanics rare.
7. Variscan folding intense.	Variscan folding slight.
8. Some Laramide folding.	No Laramide folding definitely known.
9. More intense Cenozoic folding and faulting.	Broad plateau-like late (?) Cenozoic diastrophism.
10. Average uplift small.	Average uplift greater.
11. Later erosion great.	Later erosion less.
12. Two epochs of important overthrusting.	No overthrusting.

(2) The second of these zones is followed by the Rio Grande in its eastward course from the Brewster-Terrell county line to the mouth of Pecos River and forms the northwest end of the Rio Grande embayment. Farther west it passes into an east-west syncline between the Marathon dome and the Sierra del Carmen. At its west margin this syncline is terminated by a folded, faulted, and thrust area, the Santiago Mountains, in which the trend is in general northwest-southeast and hence directly across this east-west belt. West of this folded belt is an east-west fault which is believed to indicate the westward continuation of the east-west belt. This fault, which can be followed for about 14 miles, is lost in the alluvium of Green Valley. Continued westward, this fault would pass near the south end of Chinati Mountains.

Minor east-west structures, accompanied by horizontal movement parallel to the strike of the faulting, have been noted in two localities under the description of the Eagle Mountains and in one place as described in the southern Van Horn Mountains. In all three cases the dominant structure of the adjacent territory is overthrusting.

NORTHWEST-SOUTHEAST TRENDS

The northwest-southeast folded belt of the Santiago Mountains extends from east of Elephant Mountain at Del Norte Gap to Dog

Canyon of Calamity Creek, a distance of 35 miles. In places it is markedly sinuous. West of and paralleling this belt is a northwest-southeast trending fault extending from Black Mountain to Rosillos Mountain, a distance of 18 miles. This fault is here named the Chalk Draw fault.

Other structural features with northwest-southeast trends are found in the Rosillos and Chisos mountains and thence southwestward to beyond the Rio Grande. Northwest-southeast trends are dominant in the vicinity of Lajitas including the greater Solitario uplift and in the narrow dropped block of the Long Draw near Terlingua. A number of the faults between the Solitario and the Chalk Draw fault trend either northwest or west-northwest. On the southwest the great Terlingua fault, along the northeast base of the Mesa de Anguila, which on the Mexican side of the river is called Sierra Ponce (Pl. IV), is paralleled downstream from the mouth of the Grand Canyon of Santa Helena by the course of the Rio Grande, which flows in the downthrown block not far north of the fault scarp. All these structural features are aligned at right angles to those of the older Variscan.

Other belts of mountain structures with northwest axes are the Barilla Mountains, the northeastern Davis Mountains, the Van Horn Mountains, the southern Carrizo Mountains (Pl. IV), the Eagle, Quitman, and Malone mountains, the southeastern Hueco Mountains, and the Finlay Mountains. Faults in the Glass Mountains likewise have northwestward strikes.

STRUCTURAL PATTERNS IN TRANS-PECOS TEXAS

The latest orogeny in Trans-Pecos Texas resulted in a complex structural pattern. It is notable that towards the south the Cordilleran deformation advanced eastward by two successive steps. The eastward bulge of the mountain belt will be seen by referring to the structural map (Pl. IV). Examining the region as a whole it will be seen that while the trends of the Cordilleran orogeny are prevailingly northwest-southeast, yet five trend zones may be distinguished as described below. In the northern part of the Trans-Pecos region the trends are north-south or north-northwest to south-southeast. In the central part of the area, in the region of Sierra Blanca and the Barilla Mountains, the trends are northwest-southeast.

South of the center, as in central Presidio and central Brewster counties, the trend once more turns to north-south or north-northwest to south-southeast. In Brewster County from Lajitas to the Carmen Mountains the prevailing trend is northwest-southeast. Finally in the extreme southern part of Brewster County in the vicinity of San Vicente the trend once more turns to north-south or nearly so.

The pattern thus seen to exist warrants an attempt at an explanation. It is most likely that the explanation is found in a thrust movement from the Mexican overthrust province from a direction between west and southwest, at least in a relative sense. To the north of the latitude of Marathon the eastward advance of the Cordilleran orogeny was checked to some extent by the massive, thick, and consequently structurally strong Paleozoic limestones, although the force of the thrusts also was weakening. The thrust was still able to break into numerous fault blocks the Permian limestones of the Glass Mountains, to produce the Seven Heart Gap fault zone at the south end of the Delaware Mountains and the west-northwest faults of the southeastern Diablo Plateau. The Laramide orogeny produced a broad structural sag between the Van Horn and Chinati Mountains and between the Delaware-Apache and the Glass Mountains and another in the Big Bend sunken block of southern Brewster County. It was across these lower areas of Laramide structure that the later orogenic movements advanced farther northeast. The sinuosity of the faults in the Sierra del Carmen and the west-southwest dips of its fault blocks are suggestive of thrust movements towards the east-northeast. The farther southeastern continuation of the Carmen range structural lines is known to be thrust east-northeast in northwestern Coahuila beyond a distance of 40 miles southeast of the Rio Grande.

The more complicated structure south of the Texas and Pacific Railway, so far as now known, has been set forth in the preceding parts of this paper. Very little is known as yet of the structure of most of the area covered by volcanic rocks. Some folding and faulting have been noted by the writer in the volcanic rocks along the line of the Southern Pacific Railroad and also in the belt of the 30th Parallel. Probably when the volcanic rocks are studied in detail more structural complications will be found.

The belt of cross structures followed by the Texas and Pacific Railway is a valid boundary between two structural provinces. That to the south is more closely allied with the northeastern Mexico province of overfolds and overthrusts towards the east-northeast. The province north of the cross belt, consisting of northern Trans-Pecos Texas and Trans-Pecos New Mexico, has close affinities with the Colorado plateau province.

It is notable that the course of the lower Pecos River, from Latitude 31° to the mouth of the river, is parallel to that of the Rio Grande directly to the west. This part of the Pecos Valley is consequent to a synclinal downwarp, plunging southwards and downstream. The eastward bend of the Pecos, along the 31st Parallel, has been accounted for by being within the influence of the cross belt. From Carlsbad, New Mexico, to Girvin, Texas, the Pecos traverses a belt in which there has occurred a great amount of solution of the underlying soluble residues of the Permian Castile formation.

CONCLUDING REMARKS

An adequate picture of the deformational history and relationships of any more or less arbitrarily restricted area is impossible without a consideration of its surroundings; in fact, the attempt to do so, which is far too prevalent, has led to many misconceptions and inhibited greatly the solution of that most fundamental and important of all geologic problems, the cause or causes of deformation. A due sense of proportion compels one to admit that the mountain part of Trans-Pecos Texas is but a very small division, and a marginal one at that, of the southern mountainous wedge of the North American continent. In this wedge, mountain phenomena on a really grand scale are developed not in Texas but in Mexico, southern Arizona, Nevada, and southern California. This wedge, being the narrowest part of the whole continent, is likewise the weakest and is the most highly deformed in later Cenozoic time after the partial collapse of the Mexican geosyncline and the possible disappearance by submergence of a former land mass lying off the present western and southwestern coast of Mexico.

The preceding account has demonstrated that the mountainous area of Trans-Pecos Texas is separable structurally into two well marked divisions. The dividing zone between the two, first noted by

R. T. Hill, and called the Texas Lineament by F. L. Ransome, extends from Point Conception on the Pacific Coast of southern California to Cape San Roque, the easternmost point of South America, the zone determining the northeastern coast line of South America and passing through the island of Cuba. This is deserving of a name of broader application, and the writer accordingly proposes that it shall be called the Hill Intercontinental Lineament, in honor of its worthy discoverer. It is probably the greatest single structural line of the Western Hemisphere.

North of this lineament is the Trans-Pecos rift valley province of Texas and New Mexico. This also merits its own name, the term Trans-Pecos unfortunately being inclusive of territory to the south of it. Perhaps the best term for this structural and physiographic region is the Sacramento province, from the most extensive range within it. For the mountainous section in Texas south of the lineament the name of Big Bend division of the northeastern Mexican Cordilleran (overthrust) province is probably most suitable.

Field studies by the writer have demonstrated that to the south of the Hill Lineament the northeastern Mexican mountain province is overthrust predominantly in east to northeast direction. In the southern coastal half of California, southwest of the San Andreas fault zone, it has long been known that the land is moving northwestward. N. L. Taliaferro,[38] Carl Lausen,[39] and Robert E. King[40] have lately determined that in southern Arizona and in the Sonora-Chihuahua border area there is late Cenozoic dominantly westward overthrusting. What appears to have happened is something like the forcing out of a very blunt wedge, with an edge angle nearer 180° than 90°, forming thrusts outwards from a central area. Such thrusts may be formed by the upward movement of a batholith but, for the writer at least, it is difficult to understand how the intrusion of a batholith can take place except under compressional stresses akin to those which produce thrusts.

The mosaic pattern of faulting in the southeastern Diablo Plateau, the Baylor Mountains, the northern Carrizo Mountains, and the Apache Mountains-Seven Heart Gap area and the pattern of parallel

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[38]Taliaferro, N. L., An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geol., vol. 41, pp. 12–37, 1933.

[39]Personal communication cited by N. L. Taliaferro.

[40]Personal communication.

faults in the Glass Mountains, as mapped by Philip B. King, are shown in Figure 18. Some of the slip faults at right angles to the Variscan structural axes of the Marathon area were noted by the writer in 1917.[41] Subsequent work by Philip B. King and the writer has led to the discovery of a considerable number additional transverse slip faults which run parallel to the northwest-southeast faults of the Glass Mountains in the area bordering on the northwest. On one of these zones of faulting, extending southeast from Ridge Spring to beyond Hackberry Creek and northwest from Ridge Spring through the topographic gap north of Sunshine Spring towards the low broad pass at Altuda, lateral (horizontal) displacement appears to be indicated by considerable drag of the rocks towards the southeast on the southwest side of the zone.

Farther west in the zone of the Hill Lineament detailed mapping of the El Paso folio by George B. Richardson, of the Silver City, New Mexico, folio by Sidney Paige, of the Deming, New Mexico, folio by N. H. Darton, and of the Globe and Ray, Arizona, folios by

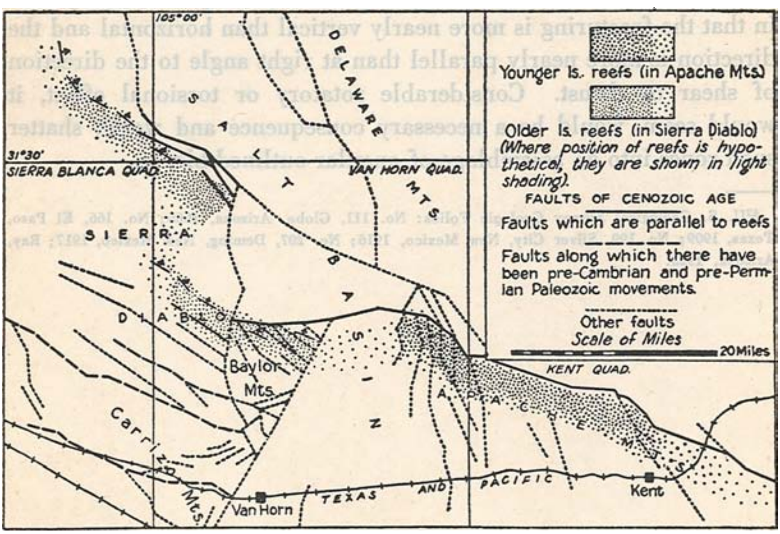

Fig. 18. Map showing faults in Sierra Diablo and Apache Mountains. After King, Bull. Geol. Soc. Amer., vol. 45, p. 740, 1934.

[41]Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of Trans-Pecos Texas: Univ. Texas Bull. 1753, p. 110, 1917.

F. L. Ransome[42] shows a remarkable fault block mosaic pattern. In southeastern Arizona, as shown on Darton's geologic map of New Mexico (U. S. Geological Survey, 1928), the zone appears to extend from the Dos Cabezas and Santa Catalina mountains on the south northwards to the southwest base of the Mogollon volcanic plateau. It is especially notable in the Ray and Globe areas that long elliptical or domical ridges composed of intricate mosaics of faulting have been uplifted in late Cenozoic time, as proved by the strong uptilting on their flanks of the late Cenozoic intermontane basin deposits of the Gila conglomerate.

An explanation is required for the phenomena so far as they are known up to the present and the writer will venture the suggestion that brittle rocks at and near the surface, without superincumbent load of other rocks, have broken into a complicated mosaic of fault blocks by lateral slip movements in a zone under compression, producing elongated-domical or elliptical areas of uplifted ridges, the longer dimensions or axes of which are nearly parallel to the diretion of lateral slippage. Therefore, they may be a consequence of thrust or shear and differ from the commonly-accepted thrust planes in that the fracturing is more nearly vertical than horizontal and the direction is more nearly parallel than at right angle to the direction of shear or thrust. Considerable rotatory or torsional effect, it would seem, would be a necessary consequence and would shatter such zones into an assemblage of angular-outlined blocks.

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[42]U. S. Geological Survey Geologic Folios: No. 111, Globe, Arizona, 1905; No. 166, El Paso, Texas, 1909; No. 199, Silver City, New Mexico, 1916; No. 207, Deming, New Mexico, 1917; Ray, Arizona, 1923.

PART 3

ECONOMIC GEOLOGY OF TEXAS

(EXCLUSIVE OF PETROLEUM)

MINERAL PRODUCTION IN TEXAS

E. H. SELLARDS

Mineral production began in Texas in a small way at a very early time. The American Indians, previous to the coming of Europeans, made some appreciable use of the mineral resources. They used flint extensively and operated flint quarries. The abundance of flint in central Texas promoted the making of flint implements which are now found in great numbers throughout most of the state. Clay was used in making pottery, pipes, ornaments, and ceremonial objects. Mineral paints, particularly the iron oxides, were much used. The Spanish, who established the earliest settlements by white men in Texas, used native stone in building some of the missions. Prospecting for minerals and some attempts at mining by the Spanish have given rise to a rich store of legends about lost mines, and no part of the state is free of such legendary accounts.

Mineral development following the settlement of Texas by emigrants from the United States progressed slowly, and records of activity in mineral development during the early history of the state are difficult to obtain. Ferdinand Roemer in his volume on Texas, published in 1849, mentions some of the mineral products of the state. The Shumard Geological Survey, established in 1857, was designed to promote the development of the then little known mineral resources. This survey terminated in 1861 but was revived and in a way continued until 1867. A general geologic report by George G. Shumard, resulting from the work of the Survey, published in 1886, mentions particularly, among the known mineral resources of the state, gypsum, salt, road materials, limestone building material, coal, iron, copper, lead, and silver.

In 1914, Dr. W. B. Phillips[1] assembled data on Texas mineral production from the earliest obtainable records to 1913 inclusive. These data, with additions, have been incorporated in the totals which follow. For the table as a whole, the writer has utilized

[1]Phillips, W. B., The mineral resources of Texas: Univ. Texas Bull. 365 (Sci. Ser., Bull 29), 362 pp., 1914.

principally data assembled by the United States Geological Survey, the United States Bureau of Mines, and the United States Bureau of the Census. Since 1883, the Federal Government has published annually reports on mineral production. From 1925 to date the Bureau of Economic Geology has coöperated with the Federal departments in collecting mineral statistics. Special acknowledgment is made to the aid of the Federal bureaus in assembling statistics of production and value.

Quantities and values given are for the most part based on shipments or sales rather than production. In products which may be easily stored, such as sulphur, production may differ materially from sales or shipments for any one year, but the totals for each are essentially in agreement when equalized through many years. The quantity given for gypsum is for amount mined, while the value given is for amount of gypsum products sold. For clay products and sand-lime brick the statistics available are those obtained by the Bureau of the Census. Many manufactured mineral products are not included, such as carbon black, of which Texas production is larger than that of all other sources. Petroleum products are for the most part not included. The natural gas quantity is that which has been recorded as passing through pipe lines and does not include the vast amount that has escaped into the air or has been used for manufacturing natural gas-gasoline and carbon black. It is estimated that to the end of 1934, 4 trillion cubic feet of gas had been withdrawn from the Amarillo field alone. Fluorspar and rare-earth minerals produced in small quantities are omitted from the totals. Briquettes and raw clay likewise are not included in the state totals.

The writer has attempted an estimate of the total production and value of some of the minerals and mineral products. For those minerals not fully reported by the producing companies, it has been necessary for this purpose to make estimates based on the best possible available data. It is recognized that totals so obtained are necessarily more or less in error, some having a large possible error, while others are much more nearly accurate. It is believed that such totals are useful since they indicate the approximate, although not the exact, total production and value of the minerals and mineral products.

Summary of Mineral Production in Texas, 1882 to 1933

		Production 1933		Estimated production 1882–1933	
	Date[a]	Quantity	Value	Quantity	Value
Asphalt	1894	126,069	$ 353,847	4,940,533	$ 37,772,884[b]
Basalt	1921	—	—[c]	—	—[h]
Cement	1882	3,091,071	5,268,605	90,048,085	148,798,891
Clay products	1882	—	1,083,051	—	125,692,926
Coal	1882	9,393	25,000	24,525,255	65,316,839[d]
Copper	1906	2,000	128	1,309,960	212,617
Fuller's earth	1907	45,395	411,350	432,340	4,269,950
Gems	1907	—	—[e]	—	—[h]
Gold	1889	—	—[e]	4,608	125,625
Granite	1882	37,020	68,260	—	5,803,533[g]
Graphite	1916	—	—[e]	—	—[h]
Greensand	1916	—	—[e]	—	—[h]
Gypsum	1882	112,106	1,058,869	7,456,063	44,402,018
Helium gas	1921	—	—[c]	—	—[h]
Iron ore	1882	—	—[e]	640,077	604,906
Lead	1907	3	222	1,890	207,935
Lignite	1882	812,485	808,000	28,586,309	33,654,237[d]
Lime	1882	36,286	339,035	1,850,369	13,270,524
Limestone	1882	687,710	850,904	—	31,009,378[g]
Manganese	1916	—	—[c]	—	—[h]
Marble	1921	—	—[e]	—	—[gh]
Mercury	1899	—	—[c]	123,777	9,139,111
Mica	1920	—	—[e]	427	8,995
Mineral water	1882	—	—[f]	55,201,030[f]	3,654,264[f]
Miscellaneous stone	1927	383,490	122,319	1,712,607	1,233,496
Natural gas	1893	475,691,000	88,264,000	3,672,402,001	605,695,207
Natural gas-gasoline	1916	366,515,000	11,562,000	3,772,888,487	228,632,713
Oil	1889	402,609,000	225,000,000	3,215,309,005[i]	3,812,117,085
Pig iron	1882	—	—[e]	150,820	3,016,397
Potassium salts	1932	—	—[e]	—	—[h]
Salt	1882	165,603	560,085	—	13,369,248
Sand and gravel	1891	4,317,312	2,264,905	98,551,829	57,296,304
Sand-lime brick	1906	—	—[c]	—	—[h]
Sandstone	1882	107,600	99,106	—	2,736,684[g]
Silver	1882	160	56	22,774,015	15,503,178
Sodium compounds	1933	—	—[c]	—	—[h]
Strontium	1904	—	—[e]	—	—[h]
Sulphur	1912	1,507,749	27,139,482	20,985,762	369,650,218[j]
Tin	1910	—	—[e]	8	6,813
Zinc	1906	—	—[e]	744	104,093
Miscellaneous	—	—	395,209	—	4,474,073
Total	—	—	365,674,433	—	5,637,780,142

[a]Earliest date at which production is reported.

[b]This total includes asphalt from bituminous rocks, 14,856 tons valued at $129,760; asphaltic limestone, partly estimated, 3,311,684 tons valued at $10,181,400; and asphalt from petroleum, partly estimated, 1,613,993 tons valued at $27,461,724.

[c]Included in miscellaneous for 1933.

[d]The total recorded for coal and lignite is 53,111,564 tons, valued at $98,971,076. The amounts assigned to coal and to lignite are in part estimates. Cannel coal is included with lignite.

[e]No production in 1933.

[f]Total to 1923. The production and value of mineral water have not been recorded since 1923.

[g]The total recorded for stone, exclusive of basalt, marble, and miscellaneous stone, is $39,549,595. The amounts assigned to granite, limestone, and sandstone are in part estimates.

[h]Included in miscellaneous. The value included in miscellaneous for helium is for the residue gas only. A value for helium gas is not included in the total for the state.

[i]The *Oil Weekly*, issue of January 28, 1935, contains record of production of oil by years and by fields or regions. The total production in Texas to the end of 1933, as recorded in this publication, is 3,428,870,774 barrels The production for 1934, estimated in part, is given as 358,128,700 barrels.

[j]Production of sulphur in Texas in 1934 was 1,187,233 tons; shipments were 1,302,663 tons. The average quoted price as reported by trade journals was $18 per ton at the mines.

Units of measurement used in reporting quantities produced are as follow: copper and graphite in pounds; cement in barrels; gold and silver in troy ounces; mercury in flasks of 75 or 76 pounds; mineral water and natural gas-gasoline in gallons; natural gas in thousand cubic feet; oil in barrels of 42 gallons; and sulphur and pig iron in tons of 2200 pounds. The quantity of all other products is given in tons of 2000 pounds. The assistance and coöperation of the producing companies in collecting statistics of production are greatly appreciated.

Texas mineral production increased from a value of about $1,000,000 in 1887 to approximately $500,000,000 in 1930. Total values by 10-year periods to 1930 and for the three years 1931 to 1933 are as follows:

1882–1890[2]	$ 10,960,520
1891–1900	33,504,079
1901–1910	140,475,890
1911–1920	928,656,019
1921–1930	3,466,166,830
1931–1933	1,058,016,804
Total	$5,637,780,142

[2]No record available for 1880 and 1881.

This record affords a striking illustration of the continued rapid advance in the value of Texas mineral production.

METEORITES

It is not customary to include meteorites as a part of the mineral resources. However, these extraneous bodies are of some commercial and of great scientific interest. The largest meteorite that has been found in Texas, the Alpine meteorite, has an estimated weight of 2 tons. The second largest known weighed 1635 pounds. It was found in north-central Texas and is now in the collection of the Peabody Museum of Natural History at Yale University. A smaller meteoric mass weighing about 320 pounds, probably of the same fall, was obtained by Captain Neighbors in 1856 and is now in The University of Texas collection. The locality for this smaller meteorite is given as on the east side of Brazos River, 60 miles from Ft. Belknap, direction not given. The following list of meteorites obtained from Texas has been kindly contributed by Oscar E.

Monnig, 312 West Leuda Street, Fort Worth, Texas. Mr. Ernest Weidhaas of Pelham Manor, New York, has written that one of the meteorites contained in the collection of the late George F. Kunz is an iron meteorite weighing 308 grams labeled as follows: "Cut Off, Quadaloupe County, Texas." Guadalupe County, Texas, early in the history of the State, was often spelled Quadaloupe. Mr. E. Gerlich informs the writer that the town of Schertz was formerly known as Cut Off, the name having been changed to Schertz in 1899.

ODESSA METEORITE CRATER

When a large meteor strikes the earth's surface, a pit or depression is formed which may be of such size and depth as to persist for many centuries. Such a depression about 7 miles southwest of Odessa, Ector County, is believed to have been made by a meteor, fragments of which have been obtained and described as the Odessa meteorite. This depression was first described by the writer in 1927.[3] At this locality there is found a crater approximating a circular form, although with a slight northeast-southwest elongation, together with some irregularities in the marginal outline. The rim of the crater rises from 5 to 7 feet above the general level of the surrounding plain. The depression is to some extent filled by wash and wind-blown material, the depth being at present from 9 to 14 feet below the rim, or 5 feet below the average of the surrounding plain. In width from rim to rim the depression measures from 500 to 650 feet. At several places around the rim of the crater the Cretaceous rocks are exposed, having been lifted appreciably from their original position, presumably by the impact of the meteor. A map of this crater made and contributed by Robert Brown and Oscar E. Monnig is given in the accompanying illustration, Figure 18A. The location of outcrop of Cretaceous rock is indicated in the sketch by hachure lines. Many fragments of an iron meteorite have been found at and around this small crater.[4] It is now certain that this depression

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[3]Sellards, E. H., Unusual structural feature in the plains region of Texas (abst.): Bull. Geol. Soc. Amer., vol. 38, p. 149, 1927.

This locality may be reached as follows: From T. & P. depot at Odessa follow highway No. 1 southwestward 8 miles, turn left through wooden gate and follow ranch road south approximately 1 mile to ranch house, continue in southerly direction through wire gate, pass under telephone line approximately 1 mile from the ranch house. One-tenth of a mile beyond the telephone line, turn left from the ranch road. The meteorite crater is located on slightly elevated land, a total distance of 10¼ miles by road from Odessa.

[4]A description of the Odessa iron meteorite was given by Geo. P. Merrill in the American Journal of Science, vol. 3, p. 339, 1922.

records the fall of a large meteor. Whether or not a part of the meteor is buried in the earth at this place is as yet undetermined.

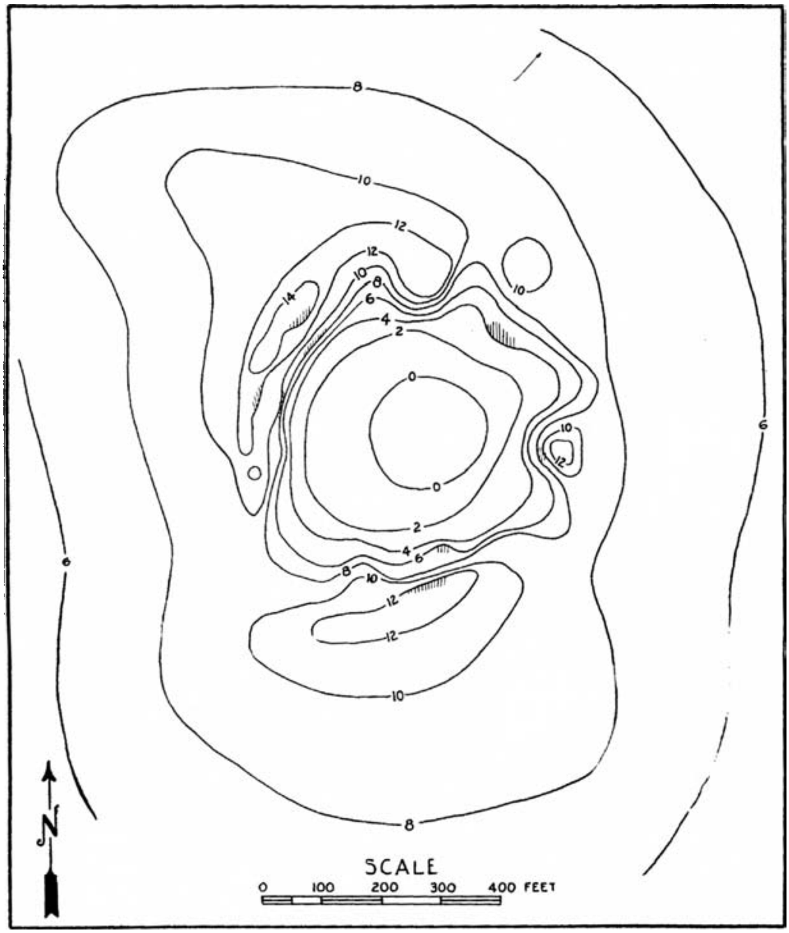

Fig. 18A. Topographic map of Odessa meteorite crater by Robert Brown and O. E. Monnig. Hachure lines indicate outcropping Cretaceous strata around the rim of the crater.

PRELIMINARY CHECK LIST OF TEXAS METEORITES

Oscar E. Monnig

1. Alpine, Brewster County. Found 1915. Single iron mass of 2 tons estimated weight. Described by G. P. Merrill, U. S. Nat. Mus. Pr. 61, art. 4: 4 pp., 1922.

2. Bluff (also referred to as "La Grange"), Fayette County. Found 1878. One stone, 145 kgs. (320 lbs.). Described by Whitfield and Merrill, Am. Jour. Sci. (3) 36: 113–119, 1888. Field Museum, Chicago, has a large portion of this.

3. Ballinger, Runnels County. Found 1927. One iron, 1250 gms. (2.7 lbs.). Described by H. H. Nininger, J. G. 37: 88–90, 1929. A part is in the collections of The University of Texas.

4. Burkett, Coleman County. Found 1913. One iron, 8.4 kgs. (18.4 lbs.).

5. Blanket, Brown County. Fell 1909, May 30, 10.30 P.M. Two stones, 3.1 kgs. (6.8 lbs.). Both in Field Museum, Chicago. Also one stone, 1815 gms., in U. S. National Museum.

6. Carlton, Hamilton County. Found 1887. One iron, 81.4 kgs. (179 lbs.). Described by E. E. Howell, Am. J. Sc. (3) 40: 223–226, 1890.

7. Cedar, Fayette County. Found about 1890 or 1900. Three stones, 14 kgs. (31 lbs.). Described by G. P. Merrill, U. S. Nat. Mus. Pr. 54: 557–561, 1918.

8. Denton County. Found 1856. One iron, 18 kgs. (40 lbs.). Described by B. F. Shumard, Ac. Sc. St. L., Tr. 1: 622–624, 1860.

9. Davis Mountains, Jeff Davis County. Found 1903. One iron, 690.9 kgs. (1,520 lbs.). Described by O. C. Farrington, Field (col.) Museum Pub. 178, g.s., 5: 1–14, 1914. Field Museum has this mass.

10. Estacado. This name comes from a town in Crosby County, but these two stone meteorites were found at a point in Hale County, about 1883. 290 kgs. (640 lbs.); perhaps the weight is more, as some lists give only one mass, whereas there were in reality two. Described by K. S. Howard and J. M. Davison, Am. J. Sc. (4) 22: 55–60, 1906. Field Museum, Chicago, has a large piece of this meteorite, and another large piece is believed to be in the American Museum of Natural History, New York (no catalog recently issued by that institution).

11. Ft. Duncan, Maverick County. Found 1850. Three irons, 160 kgs. (336 lbs.). Described by W. E. Hidden, Am. J. Sc. (3) 32: 304–306, 1886.

12. Florence, Williamson County. Found at unknown date before 1927. One stone, 3.8 kgs. (8.3 lbs.). Described by John T. Lonsdale, Am. Mineralogist 12: 398–404, 1927. One-half is in the National Museum and one-half in the collections of The University of Texas.

13. Iredell, Bosque County. Found 1898. One iron, 1.5 kgs. (3.3 lbs.). Described by W. M. Foote, Am. J. Sc. (4) 8: 415–416, 1899.

14. Kendall, Kendall County. Found 1887. One iron, 21 kgs. (36.2 lbs.).

15. McKinney, Collin County. Found 1870. Two stones, about 152 kgs. (334 lbs.). Most complete description, G. P. Merrill, Mem. Nat. Acad. Sc. 14, Mem. 4, pp. 6–7, 1925. Large masses of this meteorite are in the Field Museum, Chicago (over 57 kgs.) and the Vienna Museum (over 40 kgs.).

16. Mart, McLennan County. Found 1898. One iron, 7.2 kgs., (15.7 lbs.). Described by G. P. Merrill and H. N. Stokes, Wash. Ac. Sc. Pr. 2: 41–68, 1900.

17. Odessa, Ector County. Found 1922 and later. At least three or four major pieces, totalling perhaps 10 kgs. (22 lbs.), and innumerable fragments.

These are irons, associated with a meteorite crater. Description by G. P. Merrill, Am. J. Sc. (5) 3: 335–337, 1922. One piece in the collections of The University of Texas.

18. Pipe Creek, Bandera County. Found 1887. One stone, 13.6 kgs. (30 lbs.). Described by A. R. Ledoux, N. Y. Ac. Sc. Tr. 8: 185–187, 1889. Field Museum, Chicago, has about one-third of this meteorite.

19. Plainview, Hale County. Found 1913 and later; recent investigation proves probably fell about 1902 or 1903, early night. Over 30 stones, weighing over 100 kgs. (220 lbs.). Described by G. P. Merrill, U. S. Nat. Mus. Pr. 52: 419–422, 1917, and 54: 503–505, 1918. Principal masses in H. H. Nininger Collection, Denver, Colo.

20. Red River, sometimes referred to as "Cross-timbers." Johnson County? Found 1808. Iron, 743.2 kgs. (1,635 pounds). According to Ralph King, Proc. Texas Acad. Sci. 1934, p. 22, this is one of three iron masses known by early settlers in this region. Another of these is No. 27 of this list. The third mass reported to have been seen has not been recovered. Described by Benjamin Silliman, Jr., and T. S. Hunt, Am. J. Sc. (2) 2: 370–376, 1846. Principal mass in Yale University Museum.

21. Rosebud. This town is in Falls County, but the meteorite so named was found about 1905 in Milam County. One stone, about 56.8 kgs. (125 lbs.). Not yet described. In collection of Dept. of Geology, University of Texas, Austin, Tex.

22. San Angelo, Tom Green County. Found 1897. One iron, 88.2 kgs. (194 lbs.). Described by H. L. Preston, Am. J. Sc. (4) 5: 269–272, 1898. A part is in collections of The University of Texas.

23. San Pedro Springs, Bexar County. Found 1887. One stone, 72 gms. (2.5 oz.).

24. Travis County. Found 1889. One stone, 2.5 kgs. (5.5. lbs.).

25. Troup, Smith County. Fell 1917, Apr. 26, morning. One stone, 1 kg. (2.2 lbs.). Described by J. A. Udden, U. S. Nat. Museum Pr. 59: 471–476, 1921. Principal mass in collection of Bureau of Economic Geology, University of Texas, Austin, Tex.

26. Tulia, Swisher County. Found 1917. Two stones, 23.8 kgs. (52.4 lbs.). Described by Charles Palache and John T. Lonsdale, Am. J. Sc. (5) 13: 353–359, 1927. Larger stone, 14.88 kgs., in collection of Bureau of Economic Geology, University of Texas, Austin, Tex. Also two stones, 3200 and 3850 gms., in U. S. National Museum and one stone, 1½ lbs., in collection of Oscar E. Monnig, Fort Worth.

27. Wichita County, sometimes called "Brazos River." Found 1836. One iron, 145.4 kgs. (320 lbs.). Described by J. W. Mallet, Am. J. Sc. (3) 28: 285–288, 1884. A major portion of this meteorite is in the collection of the Bureau of Economic Geology, University of Texas, Austin, Tex.

28. Ysleta, El Paso County. Found 1926. One iron, 140.7 kgs. (309.5 lbs.).

29. Avoca, Jones County. Found 1924. One stone, 7.1 kgs. (16.1 lbs.).

30. Peck's Spring, Midland County. Found 1926. One stone, 16 kgs. (35.2 lbs.). Described by G. P. Merrill, U. S. Nat. Mus. Pr. 75 art. 16: 2 pp., 1929. Principal mass in U. S. National Museum, Washington.

31. Deport. The town for which these meteorites is named is in Lamar County, but the meteorites were found at a point in Red River County from 1926–1934. At least 26 irons, totalling over 10 kgs. (22 lbs.). Described by Charles Palache and F. A. Gonyer, Am. Mineralogist, 17: 357–359, 1932. A part is in the collections of The University of Texas.

32. Spearman, Hansford County. Recognized 1934. One iron, 10.4 kgs. (23.3 lbs.). Not yet described. H. H. Nininger Collection, Denver, Colo.

33. Boerne, Kendall County. Found about 1884. One stone 0.8 kgs. (1.8 lbs.). Not yet described. U. S. National Museum.

34. Cleburne (name tentative), Johnson County. Found about 1907. One iron, 6.6 kgs. (14.6 lbs.). Not yet described. Collection of Texas Observers, Oscar E. Monnig, Ft. Worth, Tex.

35. Kirbyville (name tentative), Jasper County. Fell about 1907, Nov. 12, 3.30 P.M. One stone, 97.7 gms. (3.4 oz.). Not yet described. Collection of Texas Observers, Oscar E. Monnig, Ft. Worth, Tex.

36. Gruever, Hansford County. Recognized 1934. One stone, 11.1 kgs. (25 lbs.). Not yet described. H. H. Nininger Collection, Denver, Colo.

37. Palo Duro, Armstrong County. Found 1934. One iron, 2.9 kgs. (6.5 lbs.). Not yet described. Collection of Texas Observers, Oscar E. Monnig, Ft. Worth, Tex.

38. Schertz, Guadalupe County. One iron, 308 grams. The George F. Kunz collection of meteorites, now in possession of Ernest Weidhaas, New York.

The foregoing list has been based primarily on data from *Our Stone-Pelted Planet*, H. H. Nininger, Houghton Mifflin Co., 1933. Such corrections and recent additions as time has afforded the writer to find have been made. Citations to descriptions have been taken largely from the bibliography in *The Geology of Texas*, Volume I, *Stratigraphy*, University of Texas Bulletin 3232, 1932. In the case of all the recent meteorites listed, the names are not official, but merely tentative, awaiting final naming by the describing author. Probable or known falls where no meteorites were ever recovered or have since been lost are not listed.

CONSTRUCTION MATERIALS, MINERAL, STONE, AND CLAY PRODUCTS, COAL, LIGNITE, AND WATER SUPPLIES

CHARLES LAURENCE BAKER*

The important mineral construction materials of Texas, some of which are considered under other headings, are as follows:

*In this and succeeding sections of Part 3, credit should be given particularly to the three following books, from which has been derived much information concerning uses: **Minerals Handbook, 1932–33, U. S. Bureau of Mines, 1933; Non-Metallic Minerals—Occurrence, Preparation, Utilization, R. B. Ladoo. McGraw-Hill Book Company, New York, 1925; and The Marketing of**

asbestos	marble
asphalt rock	quartzite
clays	sand
ceramic materials	sandstone
feldspar	serpentine
gneiss and schist	slate
granite	soapstone
gravel	trap rock (basalt and diabase)
gypsum	volcanic rocks (lavas, tuffs, and breccias)
limestone and dolomite	

This group of mineral construction materials ranks in second or third place in value among Texas mineral resources. Aside from water, which is a prime necessity for all life, at the present time the energy-producing minerals (oil, gas, coal, and lignite) rank first. It would be difficult to find another region on earth which is richer in mineral construction materials, especially those of the very highest grade, than is Texas. Up to the present, these vast resources have been utilized comparatively little, which is no doubt one of the reasons why their investigation, more notably that of clays and other ceramic materials, has lagged so far behind those of some other natural resources of the state.

The people of the United States in comparison with those of the rest of the world, the equatorial region of Africa and the Malay Archipelago only excepted, are very poorly housed. We have been content to live in wooden houses, which constitute one of the very greatest wastes in our wasteful national economy. Wooden structures are the costliest of all because of high charges for repairs and painting, insurance, and depreciation. Depreciation alone averages 4 to 5 per cent a year. The danger which fire threatens to life and property is by no means confined to monetary loss. The following figures should be instructive to every Texan. They show the usual relative proportion, although the sum total is abnormally low. In 1931 the total value of stone sold in the United States amounted to $135,085,627 while the total for Texas was only $1,285,558. Consequently, Texas with 4¾ per cent of the total population of the 49 states used less than 1 per cent of the stone sold. During the same year the amount of clay sold in the United States was 2,519,495 tons of which only 21,263 tons, again less than 1 per cent of the

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Metals and Minerals, various authors, edited by J. E. Spurr and F. E. Wormser, McGraw-Hill Book Company, New York, 1925. No pretense is made that all the uses of different mineral products are included. Completeness in this respect is an impossibility, since new uses are being developed constantly, and some are guarded more or less jealously as trade secrets.

total, were sold in Texas. Comparison with California is perhaps even more instructive, because California has the best pine, all the redwood, and easy access to the highest grade spruce, fir, and arbor vitae lumber. In 1931 California bought $6,482,202 worth of stone and $580,749 worth of clay. With less population than Texas, California used 5 times the value of stone and 13 times as much clay. Various northeastern states use more permanent building materials per capita than does California.

Values of Leading Mineral Construction Materials Produced and Sold in 1931

	United States		California		Texas	
Total	Tons	Value	Tons	Value	Tons	Value
Stone	97,933,180	$135,085,627	5,751,820	$ 6,482,202	1,347,100	$1,285,558
Talc and soapstones	163,752	1,852,472	11,605	180,582	----------	----------
Sand and gravel	153,479,044	86,280,320	9,673,523	6,222,779	6,081,134	3,809,267
Clay, crude	2,519,475	8,352,185	281,006	580,749	21,263	147,476
Gypsum	2,559,017	20,801,357	90,899	472,015	239,391	2,120,208
Cement	----	140,976,450	----	11,510,655	----	8,280,913
Asphalt rock	470,491	2,224,739	----	----	228,956	705,437
Lime	2,707,614	18,674,913	36,189	360,523	45,553	384,392

It is apparent from the above that it is only in gypsum, asphalt rock, and cement that Texas produces her per capita proportion. Gypsum and asphalt rock occur in greater quantity in Texas than in any other state.

STONE FOR BUILDING AND DECORATION

Building stones are unequally distributed in Texas. In the Gulf Coastal Plain where Upper Cretaceous and Tertiary rocks outcrop, there are found only relatively poor grades of sandstones. In the Staked Plains and Panhandle High Plains building stone is entirely absent. However, the center of the plains area of the state contains a diversity of first-class building and ornamental stone scarcely equalled elsewhere in an area of equivalent size. This is in the Llano uplift of Llano, Burnet, Mason, San Saba, McCulloch, Blanco, and Gillespie counties. This area is situated an average distance of about 250 miles by railroad and highway from Houston harbor, the same being its maximum distance from any of the more thickly populated parts of the state. Mountainous Trans-Pecos Texas also has a great wealth and diversity in first-class stone with, however, little demand because of sparseness of population.

With the exception of the Llano uplift nearly all the building stone east of Pecos River belongs to the class of limestone, magnesian limestone, and dolomite, having wide distribution in the central area in formations of Pennsylvanian, Permian, and Comanche Cretaceous ages. The scarcity of good sandstones east of Pecos River is noteworthy.

Aside from a limited development of granite and limestone there has been no great utilization of Texas stone resources during the last half-century. At present there is strong competition of concrete and clay products, but the greatest competitor of stone up to the present has been lumber, formerly abundant in eastern Texas. Dimension stone is classed commercially as granite, marble, limestone, sandstone, and slate. Other stones used in building are basalt (trap rock), various volcanic rocks, talc, soapstone, and serpentine (verde antique). All are found in quantity in Texas.

Crushed stone includes that used for railway ballast, concrete aggregate, and road metal. Broken stone includes all other types of non-dimension stone used in cement manufacture, lime manufacture, furnace flux, alkali works, riprap, agricultural limestone, refractories, asphalt fillers, calcium carbide manufacture, slate granules and flour, and other miscellaneous uses. Dolomite, aside from its uses in construction, is used for making Epsom salts, for basic lining in the Thomas and Gilchrist processes of steel making and in the manufacture of magnesium and its compounds.

Reference

Bowles, Oliver, The Stone Industries, McGraw-Hill Book Company, New York, 1934.

GNEISS AND SCHIST

Gneiss and schist are foliated, metamorphic rocks, often banded or ribboned in either straight or contorted layers composed of different minerals producing bands of different colors. These rocks, if they possess adequate structural strength, make extremely pleasing or beautiful building stones. A number of such rocks are to be found in the Llano uplift in Llano, Mason, Burnet, and Gillespie counties. One of the most promising areas is that of the high ridges between Babyhead and Little Llano River in Llano County.

Other good stone can be found in the Carrizo Mountains, west and southwest of Van Horn, in the Culberson-Hudspeth county border area.

Gneiss and schists have been utilized very little in Texas but have become very popular in the northeastern United States and in southern California. They are especially suited for random ashlar construction with slate roofs. In fact, they constitute one of the very best residential building materials although their use is by no means confined to residences. Some schists make very good flagstones, which are being used more and more in buildings and walks.

GRANITE

In addition to true granite, which occurs extensively in Texas, there are a few valuable building stones classed commercially as granites but which are really diorites, gabbros, syenites, and phonolites.

The granites of the Llano uplift occur in Llano, Mason, Burnet, Gillespie, and Blanco counties. They are of pre-Cambrian age, probably consisting of masses of various sizes and shapes projecting upwards from the main body of an extensive and still buried batholith. These granites intruded an already folded and metamorphosed complex of gneisses, schists, marbles, phyllites, slates, quartzites, and some basic igneous rocks, the last altered to serpentine, talc, soapstone, metadiorite, and metadiabase. The metamorphic rocks trend northwest-southeast, and the majority of the granite intrusions are more or less accordant to that strike although many of the exposed bodies have very irregular boundaries. Although the granitic masses are accompanied by very extensive pegmatite, aplite, and quartz dikes, which are exceedingly common in the metamorphic rocks as well as in the granites, very little metallic mineralization of the contact edges appears to have taken place, about the only contact mineral occurring in appreciable amount being pyrite. Perhaps this apparent lack of extrusive after-effect or contact mineralization is at least in part responsible for the remarkable freshness of the original minerals (generally quartz, potash-feldspar, and biotite) which compose the granite. Often these minerals are surprisingly unaltered up to virtually the actual weathered surface. However, in the northern part of the large

Katemcy granite mass in northern Mason County the feldspars are considerably dulled by probably eruptive after-effects.

Stenzel[1] divides the granites into coarse-grained Town Mountain; gray, medium-grained Oatman Creek; and gray, fine-grained Sixmile, the names being taken from localities in central Llano County. The Sixmile are cross-cutting and the youngest but are followed by dikes of quartz-porphyry and felsite.

The constructional, ornamental, and monumental granites already known to exist in quantities and sites suitable for commercial quarrying are so numerous in this region that it is possible to give here only a brief mention of some of the more beautiful stones. The Bureau of Engineering Research and the Bureau of Economic Geology have lately made a preliminary and partial investigation of the stone resources of this area, and specimens are in the collections of The University of Texas. This investigation demonstrates that the resources in first-quality granites of practically every color and texture in this district of central Texas are not known to be surpassed elsewhere on the globe. Geographically, also, their situation is excellent, being the center of the more populous part of Texas. The distance from the Llano region where these rocks occur to Houston deepwater harbor is about 250 miles.

The textures range all the way from very fine-grained statuary gray to very coarse porphyritic with feldspar phenocrysts 2 inches in size. Among the novelties are a medium, coarse brown granite with opaline quartz; a coarse-grained, whitish-gray granite lightly suffused with delicate rose-pink; a granite with medium-grained, spotted black and white groundmass with larger crystals (phenocrysts) of light pink feldspar; and a coarse-grained granite with larger crystals of bright red feldspar. Most, but not all, of the gray granites are of light shades. There are a number of desirable granite-gneisses. A stone resembling the famous Quincy granite of Massachusetts, but really a diorite (composed of white plagioclase feldspar and dark green hornblende), occurs in both medium- and coarse-grained facies at the edge of the large serpentine body on the Pierce Smith ranch in northeastern Gillespie County.

Syenites and related rocks are widely distributed in intrusive masses of Tertiary age in Trans-Pecos Texas. They are light

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[1] Stenzel, H. B., Pre-Cambrian of the Llano uplift, Texas (abstr.): Bull. Geol. Soc. Amer., vol. 43, pp. 143–144, 1932.

brownish-gray and in some localities are porphyritic. Such rocks found near rail transportation and known to be suitable for building stone occur at several localities as follows: at Iron Mountain near Marathon, Brewster County; between Chispa and the Wylie Mountains east of Lobo railroad station in Culberson County; in the central Quitman Mountains of Hudspeth County; and in the Hueco Mountains east-northeast of El Paso. Possibly there is also some merchantable stone on the west flank of the Franklin Mountains near El Paso. Suitable granites are situated 12 to 16 miles west of Fort Davis along the road from that town to Valentine and in the Quitman Mountains. Granitic rocks are found at numerous other localities in west Texas more remote from railways, but little is known of their commercial qualities. The grayish-green, very fine-grained porphyritic phonolite at Ange siding on the Southern Pacific Railroad 4 miles northeast of Uvalde is a splendid building stone of a rare and pleasing color.

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LIMESTONE AND DOLOMITE

Limestone, when pure, is a rock consisting of a single mineral, calcite, the composition of which is calcium carbonate ($CaCO_3$). Dolomite, when pure, is a double carbonate of calcium and magnesium ($CaMg(CO_3)_2$ or $CaCO_3.MgCO_3$ with 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate), also a rock composed of a single mineral. The term dolomite is often very loosely used. It is desirable to restrict this term to a rock in which the percentage of magnesium carbonate is 40 per cent or above. A rock carrying 30 to 40 per cent magnesium carbonate is classed as a dolomitic limestone. Similarly, the term magnesian limestone is applied to a rock containing up to 25 or 30 per cent magnesium carbonate. A pure dolomite contains 47.9 per cent carbon dioxide (CO_2), 30.4 per cent lime (calcium oxide, CaO), and 21.7 per cent magnesia (magnesium oxide, MgO). A pure limestone contains 44 per cent carbon dioxide and 56 per cent lime (CaO). Lime when mixed with water forms the weak base, calcium hydrate or hydroxide, $Ca(OH)_2$, which quite slowly upon exposure to the atmosphere unites with carbon dioxide to form calcium carbonate. Calcination or burning of lime consists in driving off from limestone, by heating, the carbon dioxide it contains leaving the calcium oxide as a residue.

Good limestone is fairly abundantly distributed over an area comprising about two-fifths of Texas and is lacking in the other three-fifths of the state. The whole Coastal Plain section of Cenozoic and Upper Cretaceous surface exposures is without good building stone although the various Upper Cretaceous soft chalks are well adapted for cement making and for a number of other of the very numerous uses of calcium carbonate. The High Plains section of northwest Texas, comprising the Staked Plains and the Panhandle High Plains, north of Canadian River, is likewise lacking in limestone, except for the impure caliche cap rock occurring at the margin of the escarpments. The latter is of little utility except for the construction of roads of secondary importance, although it is used more extensively in this region where exceedingly little first-class road material is available.

The caliche, which is fairly abundant in the drier parts of the state, that is, west of the 98th Meridian, is for the most part a marginal deposit near "breaks," notably where flatter country ends in steeper slopes. In such places underground waters carrying calcium bicarbonate ($H_2Ca(CO_3)_2$) in solution seep out to the surface, lose their hydrogen ion by evaporation and oxidation, and deposit their solute as relatively insoluble calcium monocarbonate ($CaCO_3$) or limestone. On the other hand, most soluble limestone is either at least in part an organic precipitate of the hard parts of plants and animals ("shell" and calcareous algal material, hard parts of corals, and animals of similar skeleton), or else an inorganic precipitate upon the supersaturation of water with calcium carbonate, either upon evaporation or rise in temperature. Many dolomites are likewise inorganic precipitates, but upon the whole the formation of dolomites is an unsolved problem.

All Paleozoic systems in Texas except the Devonian contain notable limestone deposits, and the same is true of the Lower and Middle Cretaceous. In the Cretaceous the percentage as well as the absolute amount of limestone increases from all directions toward the southern and western parts of the Big Bend country. It chances, therefore, that the most thinly populated part of the state possesses the richest limestone resources. In this part of the state, likewise, the Eagle Ford and Austin or Boquillas (Val Verde) formation of the Upper Cretaceous consists of thin- to medium-bedded limestone containing a large percentage of quite fine sand grains which makes excellent flagstones, pavements, and flooring.

Next in importance are the limestones forming a broad belt across central and north-central Texas from the Rio Grande to Red River. Their central situation is advantageous to the more populous part of the state. In this central belt in all three main systems—Pennsylvanian, Permian, and Cretaceous—the limestone increases, both in number of beds and in thickness, southwards, there being practically none along Red River, except those containing more or less magnesia in the Upper Permian. The Permian and Pennsylvanian strata become entirely covered by the Cretaceous limestones of the Edwards Plateau at varying distances to the south of the Colorado River valley.

The Llano uplift of central Texas—in San Saba, McCulloch, Lampasas, Burnet, Llano, Mason, Blanco, and Gillespie counties—contains vast resources of excellent Paleozoic building limestones and dolomites. Nearly all these, with the exception of some remarkable as well as fairly unique porcellaneous-textured dolomites of the Ellenburger group, will take a high polish and hence are classed as commercial marbles, although in the strict geologic sense they are not marbles.

The Wilberns formation of Upper Cambrian age contains at least one valuable horizon of "edgewise conglomerate" of flattened, light-greenish pebbles in a brownish matrix, extensively developed in southern San Saba County, which is a remarkable ornamental stone for the interiors of buildings, suitable for walls, wainscoting, baseboards, pillars, columns, and trim. The same formation in the same area contains a thick horizon of a mottled, dark golden-yellow and brownish-buff stone suitable for the same purposes as the "edgewise conglomerate." The latter is a so-called "Girvanella rock." This is also a good stone for building exteriors, as may be seen from the old college building, now the public school building, in Cherokee, southeastern San Saba County, which is constructed of this stone.

The Ellenburger group of the counties of the Llano uplift exhibits a variety of first-class building limestones, magnesian limestones, and dolomites scarcely surpassed anywhere else. One of the largest marble concerns in the United States formerly operated quarries in this group in the vicinity of the town of San Saba, marketing the product as marble. Unfortunately, the quarry sites, with the exception of the Buffalo Rock quarry, on Buffalo Creek, about 9½ miles in a direct line south and a little east of San Saba, were not well chosen, either from the standpoint of quality of stone or from that of transportation facilities. In the localities where the quarries are located the stone contains either nodules of chert or an unfavorable amount of easily decomposed marcasite. A painstaking investigation by G. A. Parkinson and the writer has fully demonstrated the extraordinary richness of the Ellenburger group in strictly first-class limestones and dolomites, occurring in many places throughout the region in entirely feasible quarry sites with thicknesses of marketable stone entirely adequate in supply.

It is impossible to describe herein all these remarkable excellent building stones of the Ellenburger group. There are doubtless many localities which have not yet been found. Specimens of a large assemblage may be examined in the collections at The University of Texas. Due care must be exercised in the choice of quarrying sites, especially safeguarding against cherty stone and that containing marcasite which is apt to discolor or decompose the stone. Taking these precautions and exercising ordinary good judgment with respect to accessibility, keeping water out of the quarries, and otherwise economical quarrying, many different varieties of remarkably attractive and otherwise excellent stones can be successfully developed in the Ellenburger group.

Good examples of rock face masonry construction from light-gray, dense Ellenburger can be seen in the two churches in the northwest part of the town of San Saba and in the church at Doss, Gillespie County. Good stone exists within a short distance of the Southern Pacific Railroad tracks along Honey Creek, Burnet County, and in the territory south of Burnet. These particular Burnet County rocks are dolomitic and mostly fine grained.

There are a number of the finer-grained Ellenburger stones streaked in many different patterns with light-green, red, pink, brown, and yellow shades. The denser, very fine-grained, light-buff, or cream-colored porcellaneous to lithographic-textured stones in some cases take a fine polish and in other cases produce very desirable honed or sawed finish suitable for either exterior or interior construction. Finely laminated stone, in some cases with wavy laminae, when polished resembles some fine-grained hardwoods. Another notable stone has irregular mottling of dark-maroon or purplish color in a gray-buff matrix. Some of the stones with stylolites are sufficiently consolidated to pass tests for strength and produce very satisfactory commercial marbles. Most of the commercial stone of the Ellenburger is dense and fine grained, some of it being fairly highly siliceous but without undesirable chert accumulations. Some of this can be used for steps, flooring, and flagging, being notably resistant to abrasion.

There is an exposure of one solid bed of medium coarsely crystalline limestone of Boone Middle Mississippian age in a vertical bluff on the east side of Honey Creek a short distance upstream from the Mason-White ranch road crossing in Mason County. This rock is of a light creamy-buff color and polishes well.

Most of the Marble Falls limestone of Lower Pennsylvanian age in the Llano uplift is siliceous and either black or dark blue-gray. Some of the thinner-bedded stone is suitable for flagging. There is a beautiful stone of black groundmass with white crystalline crinoid stems which can be used for interior ornamentation or desk ornaments. A large quantity of bituminous Marble Falls limestone located 7½ to 8 miles in a direct line very slightly east of south of Richland Springs, San Saba County, has intricate mottlings of yellow, brown, and lavender contrasted with black. All the Marble Falls limestones take a high polish, the solid black stones being fully equal in quality to the finest imported black marbles.

The Pennsylvanian limestones of the Canyon and Cisco formations of north-central Texas and the Permian of the Wichita formation have a number of limestones suitable for many purposes. Those farther west in the Clear Fork and Double Mountain groups of the Permian range in composition from magnesian limestones to dolomites. Most of the dolomitic stones are gray or buff, as are those of the Pennsylvanian and Permian, but some are of uniform pink color.

Paleozoic limestones are widespread and very abundant in Trans-Pecos Texas in two sections, the northern half comprising Culberson, Hudspeth, and El Paso counties and in the Marathon basin and the Glass Mountains in north-central Brewster County and central-southwest Pecos County. In the Franklin Mountains from El Paso northwards there are sugary-textured dolomite (Fusselman formation of the middle Silurian) and limestones and magnesian limestones of the Ordovician (El Paso and Montoya formations) and of the Pennsylvanian and Permian (Magdalena and Gym formations). All these limestone formations are quite thick and contain large proportions of non-cherty stone. Limestones of the same formations outcrop in the south and east margins of the Diablo Plateau and Baylor Mountains north and northwest of Van Horn. All the limestones of the Franklin Mountains outcrop in the Hueco Mountains. Extensive Permian limestones outcrop near the Texas and Pacific Railway tracks in the Wylie and Apache mountains, where some of them are dolomites and dolomitic, and near Eagle Flat station. The Southern Pacific Railroad tracks skirt Permian limestones between Fay and Collado switches at the north base of the Van Horn Mountains in southwestern Culberson County. There are vast deposits of Permian limestones, magnesian limestones, dolomitic limestones, and dolomites in the Glass Mountains of northern Brewster County. Some of the Lower Ordovician and Pennsylvanian limestones of the Marathon basin have limestones utilizable to good advantage at least locally.

The Lower and Middle Cretaceous limestones of central Texas are commercially important from Brazos River basin southwards to Colorado River and thence westwards to the Pecos. The Glen Rose, Walnut, Comanche Peak, Edwards, and Georgetown formations afford good building dimension stone, crushed rock, lime, cement, and chemical products stone. Some of the building stone is considered to be the equal of any produced in the United States. Many take a high polish. The "Austin marble" or "Caen" stone consists of translucent to transparent calcitized fossil shells in a cream-buff, fine-grained matrix. Most of these stones are solid gray, cream, or buff in color, but some are variegated. The Edwards formation contains some dolomites and dolomitic limestones.

The number of patents bearing on the utilization of dolomite for the production of refractories, magnesium cements, chemicals, and metallic magnesium have lately increased and show that dolomite, because of its widespread occurrence, must be considered an increasingly important competitor of magnesite (magnesium carbonate). Many refractories now containing chromium are apt to be supplanted by those containing magnesium, thereby saving chromium for more important and essential, non-destructible products. Dolomite is now used for basic magnesium carbonate, carbon dioxide, refractory stone, Epsom salts, and basic steel. Dolomite lime is used for mortar, refractory (dead-burned dolomites), and sulphite pulp.

Limestone and dolomite have a greater variety of uses than any other metallic or non-metallic mineral substances. They comprise more than 80 per cent of all the crushed stone produced in the United States. The following are the main uses:

Riprap
Crushed stone (for roads, concrete aggregate, railroad ballast, etc.)
Fluxing stone (in metallurgy, especially that of iron and steel)
Beet sugar manufacture
Glass manufacture
Paper manufacture
Agricultural lime (fertilizer, soil conditioner, corrective of acidity)
Alkali manufacture
Asphalt filler
Calcium carbide manufacture
Carbonic acid manufacture
Coal-mine dusting (to prevent explosions)
Fertilizer filler
Sewage filter beds
Magnesia works (dolomite)
Mineral food
Mineral or rock wool
Poultry grit
Refractory stone (dolomite)
Road base
Roofing gravel
Stucco, terrazzo and artificial stone
Whiting, whiting substitutes and chalk
Portland cement (including "cement rock")
Natural cement rock
Lime
In ammonia, baking powder, lime burners, nitrates, phosphates, powder, purification of copper, reduction of aluminum ore, soap, sulphuric acid, etc.

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CEMENT AND LIME

Cement usually consists of about 4 parts of high-grade limestone mixed with 1 part of clay or shale, with about 3 per cent of gypsum added for a retarder to the cement clinker before final grinding. Portland cement consists essentially of 60 to 70 per cent calcium oxide (CaO), 20 to 25 per cent silica (SiO_2), and 5 to 12 per cent alumina (Al_2O_3) and iron oxides. The rock used should be free of concretions of iron minerals, should have little free silica in the form of chert, flint, or quartz, and should also be free of such silicate minerals as tremolite or diopside. The rock should be so low in magnesia (MgO) that there will not be more than 5 per cent of it in the finished product, the ferric oxide (Fe_2O_3) content should not be more than 4 per cent in the finished product, and the content of sulphur should be low. The proper materials are ground, mixed, burned to clinker, and then re-ground to the desired fineness. Natural cement rock contains the necessary ingredients in proper proportion without mixing.

Lime is either calcium oxide (CaO) or the combined oxides of calcium and magnesium (MgO). Limestone or magnesian limestone is heated to a temperature at which the carbon dioxide (CO_2) is driven off: $CaCo_3$ (limestone) + heat = CaO (lime) + CO_2. One hundred pounds of pure limestone yields 56 pounds of lime. Most lime is burned in vertical shaft kilns into which are dumped limestone fragments varying from 4 to 12 inches in size. Two or more fire boxes or grates with the fuel are situated near the bottom of the shaft. The heat rising in the shaft calcines the stone which thereupon sinks below the grate level and is removed from the bottom. Some lime is made in rotary kilns similar to those used in making cement. High-calcium limes are used mainly for mortars and chemical purposes. Highly plastic magnesian limes (sometimes made from dolomite) are used mainly for finishing plasters. Total carbonate content of the stone used ranges from 97 to 99 per cent; other substances, or impurities, are undesirable. Porous, friable limestones are unsuitable because fine materials are wasted generally and they also retard the draft in shaft kilns. In 1929, 53.7 per cent of all lime produced was used in the chemical industries, 38.4 per cent for mortar and plaster, and 7.9 per cent for liming land. Lime is stated to be essential in more than 120 manufacturing industries.

Hydraulic limes have a considerable percentage (7 to 17 per cent) of silica; they slake and set slowly but have little strength unless mixed with sand. They are, however, used to a large extent in Europe. About 1¼ tons of pure limestone are used in manufacturing 1 ton of soda ash (sodium carbonate). Hydrated lime, because more satisfactorily and easily used than the ordinary quicklime, is now produced in large amounts. It is made by grinding lump quicklime to fairly uniform and fine size, thoroughly mixing it with the proper amount of water, and finely sieving or pulverizing the slaked lime to a uniform fine powder.

The cement plants of the state utilize clays, marls, and limestones of Cretaceous age. At Fort Worth the rock used for cement is of Washita Cretaceous; at El Paso, Eagle Ford shales and upper Washita limestone are used; at Eagle Ford, Dallas County, and Waco the Eagle Ford clay and Austin chalk are used; at San Antonio the two plants use a natural cement marl of the transition beds between the Austin chalk and the Taylor marl. The two plants near Houston use mussel shells from the Gulf Coast beaches and reefs for their lime. Suitable clay or marl and limestone deposits for cement manufacture exist in closely adjacent areas or together in many places in the Cretaceous and Pennsylvanian outcrop areas. The lime plants at present operative in the state are at El Paso, Austin, New Braunfels in Comal County, Round Rock in Williamson County, and Lime City in Coryell County. Lime can be produced at many other localities. Limestone is now being produced at various places from deposits of Pennsylvanian, Permian, and Cretaceous age. The production of cement in Texas during 1933 was 3,091,071 barrels valued at $5,268,605. The production of lime during 1933 was 36,286 tons valued at $339,035.

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MARBLE

Marble, in the strict sense, is a metamorphosed, crystalline rock, composed mainly of calcium carbonate or of that compound together with magnesian carbonate, in which case the marble is termed either dolomitic or magnesian. Some marbles contain small percentages of silicates or of cherty silica. The marbles of Texas are either single uniform colors varying from white through gray to black or else banded, striped, mottled, or variegated with different colors. Most of the pre-Cambrian marbles of the Llano and Van Horn uplifts have been metamorphosed by widespread dynamo-regional processes; the marbles of formations later than pre-Cambrian are formed by local or contact metamorphism of igneous intrusions. In the Llano uplift of Llano, Mason, and Burnet counties, there is a formation of marbles lying adjacent to one of quartzites. This is repeated in a number of places by folding and faulting and in some places, as east of Oxford, Llano County, the marble appears to be repeated a number of times in close parallel folds. The collections at The University of Texas contain a number of samples of various commercial marbles from this district, which show different stones of excellent quality and wide diversity in colors, banding, textures, and other features. The Millican group, outcropping between the Texas and Pacific Railway and the southern scarp of the Sierra Diablo in Hudspeth and Culberson counties contains marble, the commercial value of which is unknown.

There is marble of Permian age flanking the diorite intrusion in Marble Canyon in the Sierra Diablo scarp 3½ miles southwest of the Figure 2 ranch handquarters and 27½ miles in an air line north of Van Horn. This is high grade and pink to white in color. The locality is near the center of the west line of Culberson County. There is a white marble of Permian age one-half mile north of Eagle Spring, at the north base of Eagle Mountain, about 5 miles southwest of Hot Wells station, southeastern Hudspeth County. Both black and white variegated marble of Cretaceous age occur at the Jordan quarry of Cienega Mountain, 20 miles south of Alpine, Brewster County. The white marble has a bluish tinge, and the black has white to translucent fossil shells. Both are of excellent grade. There is another outcrop of Cretaceous marble in Jeff Davis County, 7 miles north-northeast of Wendell section house.

Limestones and dolomites capable of high polish and known commercially as marbles are described in the section on limestone.

SANDSTONE AND QUARTZITE

Sandstone is a sedimentary rock generally composed chiefly of small grains of quartz (silica, SiO_2) sand. However, some sandstones are composed of arkose, which is a mixture of disintegrated, not greatly decomposed ("weathered") minerals derived from igneous or metamorphic rocks, and contain as chief ingredients feldspars, micas, or hornblendes (amphiboles), pyroxene, secondarily serpentinized minerals and other minerals. The commoner substances cementing sandstones are calcium carbonate, silica, or iron oxide, although sometimes the cement is composed of clayey minerals. A quartzitic sandstone is one that is hard, dense, and cemented by silica. The sandstone of the Catahoula formation of the Gulf Coastal Plain is cemented by the form of silica known as milky-white opal, or the cement may be another silica mineral or chalcedony.

Good sandstone building stones are somewhat rare east of Pecos River. There exist, however, a number of sandstones suitable for building purposes in localities fairly close to their outcrops. One of these is the Hickory buff to brown sandstone of Upper Cambrian age outcropping in central Texas in Llano, Mason, Burnet, Gillespie, Blanco, San Saba, and McCulloch counties. Another is the fine-grained, blue-gray sandstone occurring in thin beds interbedded with clays in the Smithwick formation of Pennsylvanian age in the valley of Colorado River between Marble Falls and Smithwick in Burnet County. This is suitable also for grindstones, whetstones, and flagging.

Locally, sandstones sufficiently indurated for building purposes occur in the Strawn, Canyon, and Cisco formations of the Pennsylvanian as well as in the Wichita, Clear Fork, and Double Mountain Permian formations of north-central Texas. In general, these sandstones become more abundant northwards towards Red River. Some of the Upper Triassic sandstones of northwest Texas are likewise utilizable locally. The "brownstone" near Quito, Ward County, formerly used for building dimension stone along the Texas and Pacific Railway at least as far east as Fort Worth, is supposed to be of Upper Triassic age. Its cementing material is gypsite

($CaSO_4 + 10\ H_2O$), and it is possible that it is really of late Cenozoic age. Its color is really dark red, and it is an easily worked stone though rather soft.

In places the Trinity and Woodbine formations of the Cretaceous have local deposits of sandstone in the northeast and central parts of the state as well as on the northern border of the Edwards Plateau and outliers to the north. Thin sandstones of the Navarro group of the Upper Cretaceous, interbedded with clays, occur in Maverick County in the vicinity of Eagle Pass and also in southern Uvalde County. These are fine grained, dense, fairly well consolidated, and have a pleasing blue-gray color when fresh which weathers to buff or brownish-buff upon prolonged exposure.

The Claiborne and Wilcox groups of the Eocene contain local utilizable deposits of yellow, brown, or reddish sandstones along their outcropping belts from northeast Texas to where they cross the Rio Grande in Webb County. These generally have iron oxide as cementing material. The Catahoula (Oligocene?) contains fairly extensive lenses of opaline-cemented quartzitic sandstone which has been used for jetty construction in Gulf Coast harbors as well as for riprap, fills, rubble-masonry, crushed rock, and railway ballast. The principal quarries are in east Texas in southern Angelina, northern Polk, and in Tyler, Jasper, and Grimes counties. Notable deposits occur in Walker County.

Good building sandstones are widespread in Trans-Pecos Texas. The oldest of these sandstones are those of the pre-Cambrian Millican group of red sandstones and conglomerates in the Van Horn area, mostly within a few miles to the north of the Texas and Pacific Railway. In the same locality are the Van Horn formation sandstones of buff, gray, brown, and red colors. In the Franklin and Hueco mountains near El Paso is the Bliss Upper Cambrian sandstone, prevailingly fine grained, gray to brown in color, and locally quartzitic.

The Marathon basin of northern Brewster County contains abundant sandstones in the Tesnus and Haymond formations of the Carboniferous. Most of these are hard, dense, fine to medium textured and of green to gray color when fresh, weathering to tan, rusty-brown, or reddish shades. Locally, especially in the Tesnus, they are quartzitic. The sandstones are often arkosic, the greenish colors being caused by admixture of chloritic minerals.

Trinity Cretaceous sandstones are widespread in Trans-Pecos Texas. The Maxon sandstone of this age outcrops around the east and southeast borders of the Marathon basin where it is exposed close to the Southern Pacific Railroad from the vicinity of Maxon siding eastwards to near Longfellow siding. The Maxon is generally brown, much thicker, and more extensive than the basal sandstones of the Trinity. Trinity sandstones of the Cox formation outcrop relatively close to the railway lines in southwestern Culberson and southeastern Hudspeth counties from the Van Horn Mountains on the east to beyond Sierra Blanca on the west. The Cox sandstones range in color from buff through brown to red, and several strata are hard, dense, and firmly cemented. In the same locality are some yellow, tan, or brown sandstones of Del Rio Cretaceous age. These thick-bedded sandstones in the Del Rio formation, red-brown or white in color, outcrop also in the Cerro Muleros, just southwest of El Paso.

A true quartzite is a rock in which the grains of quartz in the original sand have received additions of silica which crystallize so as to restore as far as may be possible the original crystal forms of the sand grains. Most often a like process going on with the surrounding grains causes an intergrowth or interlocking so that a quartzite breaks across the original sand grains. A sandstone, on the other hand, breaks around the sand grains by fracturing through the cementing material or matrix. Locally in Texas, as in the Catahoula formation of most probably Oligocene age, quartzites or at least quartzitic sandstones may form from relatively young rocks, but most of the true quartzites are in the dynamo — or regional — metamorphic rocks of the pre-Cambrian or in contact-metamorphosed rocks of any age where formed by heat and mineralizing solutions and vapors of originally molten igneous rocks.

A formation of light-buff, cream-colored, or whitish quartzite is found in the pre-Cambrian of the Llano uplift in Llano, Mason, and Gillespie counties, central Texas, which has not yet been given a formational name. This quartzite formation is closely associated with a marble formation, and the two will afford probably the best guide rocks for the structural, areal, and stratigraphic study of the pre-Cambrian metamorphic series whenever the study may be undertaken. The quartzite, which is generally rather finely crystalline, hard, and dense, and structurally of great strength though somewhat brittle and breaking with a glassy fracture, contains a large amount of pyrite in small, cubical crystals. This pyrite decomposes rather readily under processes of weathering. Pyrite is a mineral which occurs commonly in many different kinds of rocks. Where it occurs in such rocks as limestones, dolomites, and in some but not all igneous and metamorphic rocks, its decomposition, where water and oxygen are present as in surface or near-surface weathering, generates sulphuric acid which decomposes, dissolves, discolors, and disintegrates the containing rock, if the rock is of a chemical composition susceptible to such weathering processes. This quartzite, however, cannot be acted upon by sulphuric acid, and hence the decomposition of the pyrite merely serves to discolor the quartzite with yellow, brown, or red iron oxide formed from the iron in the original pyrite. Consequently, the weathered quartzite is stained, streaked, or mottled without in any way impairing its strength or qualities of permanence. For some purposes this quartzite is desirable.

The Lanoria quartzite of pre-Cambrian age outcrops along the eastern flank of the Franklin Mountains, north of El Paso. The rock is alternately thick and thin bedded. Some of it is almost white, and other parts are dark colored, though the most usual color is gray. It is fine textured and thoroughly cemented and is made up of rounded and subangular grains of quartz in a matrix of silica, sericite, and kaolin. It is usually massive and even bedded in layers about 2 feet thick. The formation dips westward and is cut by two sets of joints, one north-south and the other east-west, the joints dipping at steep angles.

SERPENTINE

Serpentine is a rock composed of the mineral serpentine. This mineral is always an alteration or secondary product. In composition it is an hydrous magnesian silicate ($H_4Mg_3Si_2O_9$). All three kinds of secondary alterations producing serpentine probably have been operative in Texas. Alteration by ordinary weathering or by the decomposing action of sea water, from original basic igneous rock (dolerite, diabase, and basalt) either in lava flows, volcanic fragmentals as tuffs, lapilli, or bombs, or as intrusive bodies, such as necks, stocks, plugs, dikes, sills, or laccoliths, has formed probably at least most of the serpentines found in the Upper Cretaceous rocks of the Balcones fault zone from Williamson and Bastrop counties on the east westwards to the Rio Grande in Kinney County. In localities of favorable structure, and where these serpentines are porous, they afford reservoir rocks for petroleum (as in the oil fields of Williamson, Travis, and Bastrop counties). These serpentines, pulverized and mixed with sand, ground limestone, or caliche, and thoroughly compacted by wetting or rolling, may be used for walks, paths, and tennis courts.

The older serpentines, of pre-Cambrian age, outcrop in the Llano uplift, particularly in the large serpentine mass of the common boundary area of Gillespie, Blanco, and Llano counties, and at the following localities in Llano County: Phillips and Moss ranches in the ridge a short distance west of the Llano-Oxford road, the Aaron Rhode ranch near the southwest corner of the county, and in the Crabapple Creek basin on the Holman and Ehlers ranches. East of the last area and to the north or northeast of the large area, 5 square miles or more in extent, of the common boundary area of Llano, Blanco, and Gillespie counties, there may be other outcrops; at least, there are a number of partly serpentinized, copper-sulphide bearing metadiabases and metadiorites known there. The amphibole asbestos, described in the section on asbestos, occurs in the serpentines of the Llano uplift, as do some chromite and magnetite, and there is some possibility of nickel and platinum ores occurring also in the serpentine.

The Llano uplift serpentines may be in part formed by ordinary weathering or cooler water alteration or decomposition, but hot waters or vapors accompanying either igneous activity or contact or regional metamorphism and acting either on the basic igneous rocks or on limestone, magnesian limestones, and dolomites may have produced them. Serpentine is an alteration of non-aluminous silicates containing magnesia, but silica and magnesia may have been added to original limestones through metamorphic processes. There are in the area amphibolite or hornblende schists, vesuvianite and garnet rocks, and talc and soapstone which may in some places have been altered to serpentine. The large serpentine mass at the common boundary of the three counties has pretty generally a bordering rim of talc or soapstone. There is a beautiful lacelike serpentine on the border of this mass on the Gould Davis ranch in northernmost Blanco County which resembles masses in the Permian magnesian limestones of England interpreted as concretionary by W. A. Tarr.[2] Epidote, which consists of anhydrous lime, alumina, and iron silicate ($HCa_2(AlFe)_3 Si_3O_{13}$), is another mineral of fairly common occurrence in the border zone of this large serpentine mass.

A number of samples of these serpentines can be seen in the collections of The University of Texas. Many are highly ornamental "verde antiques" of commercial value. They range in color from very light to very dark green, and a number are pleasingly mottled and veined. These rocks are suitable for interior building ornamentation, store fronts, table tops, counters, and soda fountains and for the carving of small ornaments. Serpentine or "verde antique" should never be used for exterior construction exposed to the weather because it rapidly discolors, decomposes, and disintegrates.

SLATE AND PHYLLITE

Slate is a metamorphic rock derived from clay, shale, or volcanic tuff. Its distinguishing characteristics are foliation with slaty parallel cleavage by means of which the rock will split into large parallel and very thin sheets and constituent minerals so fine that they can not be distinguished by the unaided eye. Phyllites have the parallel foliation and easy cleavage of slates, but the mineral particles are larger and readily distinguishable by the eye. The platy micaceous minerals in phyllites are glistening or shiny along and parallel to the cleavage planes. Phyllites have been subjected generally to a higher degree of metamorphism than slates, being rocks intermediate between less metamorphosed slates and highly metamorphosed mica-schists. In both slates and phyllites pressure during metamorphism has arranged the different mineral particles with their longer dimensions parallel to the planes of cleavage or foliation.

True shales are likewise finely laminated, but they are softer and less coherent rocks than slates and from them it is impossible to procure thin and tough sheets of large dimensions. The minerals of slates can be seen under the microscope to be crystalline, whereas

[2]Tarr, W. A., Origin of the concretionary structures of the magnesian limestone at Sunderland, England: Jour. Geol., vol. 61, pp. 268–287, 1933.

a large proportion of the fine particles of shales are colloidal and extremely fine in grain and texture. Clay is a sticky, non-laminated rock softer than shale. Clay and shale are often confused. A shale when pulverized by the drill breaks into flattish, flaky particles, while clay drills up into mud. There is no shale in the ordinary Cretaceous and Tertiary sediments of Texas and relatively very little in the Permian and Pennsylvanian of the state. The Lower Pennsylvanian or Bend series of Texas, however, has true shales in the Smithwick formation, and shales occur in formations of age greater than Pennsylvanian.

Slates occur in the pre-Cambrian rocks of the Llano uplift of central Texas. They occur in quantity in the area surrounding Packsaddle Mountain in eastern Llano County, more especially perhaps in the Sandy Creek drainage basin south of that mountain. There the slates are black and carbonaceous. In localities where they are more highly metamorphosed they become graphitic schists.

Phyllites outcrop in a closely pressed overturned syncline in the north bluff of Beaver Creek, Mason County, from the bridge on the Fredericksburg-Mason road downstream for nearly half a mile. About 2½ miles farther southeast on the highway, at a place about 14½ miles from Mason, phyllites are exposed. Other exposures were noted on creeks some miles farther northwest of these localities, south of Llano River on the next creek northwest of Beaver Creek and also on the Otto Hoffman ranch between the Mason-Brady and Mason-Menard roads north of the narrow Lower Cretaceous ridge known as the Mason Mountains. The colors are generally gray, green, or black, and sometimes reddish.

The Carrizo Mountain pre-Cambrian metamorphic group of the Van Horn uplift in the southern border area of Hudspeth and Culberson counties, Trans-Pecos Texas, may possibly have commercially valuable slates or phyllites.

The demand for slates and phyllites, owing to the competition of other materials, many of which are artificially fabricated, has decreased during recent years. There is so high a percentage of waste in the industry that one of the most pressing problems is the utilization of the materials now wasted. The uses of slate and phyllite are for roofing slate, slate pencils, mill stock, marbleized slate, slate granules, and pulverized slate. The term "mill stock" covers rough or finished slate for structural purposes in interior building finish. It includes slate for structural and other purposes, such as flagging, sidewalks, flooring and tiles, sinks, mantels, drip-boards, shower stalls, toilet stalls, stair risers, insulating wall boards, grave vaults and covers, billiard table tops, electrical insulation and switchboard material, blackboards and bulletin boards, school slates, marbleized slate, crushed slate, and ground slate. Pennsylvania leads in slate production, with important quantities produced in Maine, New York, Vermont, Maryland, and Virginia, with a small production of roofing slate and flagging from Montgomery County, Arkansas, and Inyo, Eldorado, and Merced counties, California.

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TALC AND SOAPSTONE

Some talc is present in all real soapstones, and there is similarity in the uses of the two substances. Mineralogically both are acid metasilicates of magnesia ($H_2Mg_3(SiO_3)_4$). Both are very soft and have a greasy feel. They are usually foliated and massive but sometimes occur in globular and star-shaped groups. They may be coarse, fine grained, or fibrous; rarely in tabular crystals. The lustre is pearly, and the more usual colors are some shade of green or gray, varying to white or silvery-white. Soapstone as a rock is of variable composition, consisting, however, chiefly of talc, actinolite, and chlorite. Soapstone or steatite is the massive variety.

Talc and soapstone are widely distributed in the pre-Cambrian metamorphic rocks of Llano, Gillespie, Burnet, and Mason counties. They are always secondary, having been formed by the hydration of magnesian silicates. They are associated with serpentine, talcose, or chloritic schist, and with dolomite and marble. The minerals from which they are derived are chrysolite (olivine or peridot), hypersthene, pyroxene, amphibole (hornblende), and other magnesian silicates which do not contain aluminum. Limestone, magnesian limestone, and dolomite when metamorphosed, mainly perhaps by contact metamorphism where magnesium is added but also by regional or dynamic metamorphism where the original rock contained sufficient magnesium, can yield magnesian silicates. Basic igneous rocks, either surface flows or subsurface intrusions, can be altered by hydration to talc and soapstone. They are found in the central Texas area in the metamorphic, the igneous, and the metamorphosed igneous rocks. A zone of them surrounds the large serpentine mass in the northeast corner of Gillespie County, and the next most important belt extends northward from this mass to Honey Creek, lying to the east of Riley and Cedar mountains. Some exposures show schistose structure, and probably in them the change to talc took place during or previous to the regional metamorphism. In other cases the alteration (hydration) may have been subsequent to regional metamorphism.

A small amount of massive talc (steatite) is shaped into insulators, crayons, and other forms comparable to soapstone products, and a small amount of soapstone is powdered and sold for the same purposes as low grade ground talc. Nearly all talc is sold pulverized, while nearly all soapstone is sold as slabs or blocks. Ground talc is used in large amounts as a filler in paper, paint, rubber, textiles (cotton goods), and other products. It is also used in foundry facings, lubricants, toilet preparations (talcum powder), in ceramics and glass making, as a polisher for glass, peanuts, and rice, and as an insecticide and insulator. Much low grade talc is used in composition roofing. Lately much has been used in saggers in the ceramics industries. There are at least sixty different uses for talc. Certain massive talcs (soapstones) free from iron oxide or grit and without cracks and cleavage planes are used for the manufacture of so-called "lava" products—electrical fittings, bushings, blocks, tubes, disks, and threaded cores. Soapstone has electrical resistance and will harden when heated. Therefore, after being carved into any desired shape, it is heated to about 1100° Centigrade, whereupon it is calcined hard enough to cut glass and yet upon cooling will still possess unimpaired its original shape. The purer forms of soapstone are used mainly for electrical insulation. Crayons, pencils, and French or tailor's chalk are made from it. Impure material is very suitable for rock-dusting coal mines to reduce danger of explosions. Soapstone is used also for wash tubs, sinks, table tops, switchboards, hearth stones, warming bricks, furnace and oven linings, tips for gas burners, carved ornaments, and as a building material for spandrels, baseboards, and floor tile. It is itself an excellent dimension stone. At present about $3,000,000 worth of talc and soapstone is sold each year in the United States, most of them being produced in New York, Vermont, North Carolina, and California.

Reference

Ladoo, R. B., Talc and soapstone; their mining, milling, products, and uses: U. S. Bur. Mines, Bull. 213, 133 pp., 1923.

TRAP ROCK

Trap rock is generally a very hard, dense, very fine-textured, dark blue-gray, to black, basic igneous rock, which when weathered is changed to serpentine and then has greenish to bluish color. Soils produced from weathering of trap rock are ordinarily reddish to brownish-chocolate varying to very dark brownish-black, or even greenish-brown or yellowish. Fresh or unaltered trap rock which has flowed from volcanoes is known as basalt or in some cases basic andesite. Where it is intrusive (or cooled from a molten magma beneath the then-existing surface) it is known as dolerite, diabase, or gabbro, depending upon its composition. Some of the intrusives may range from finely to coarsely crystalline.

Outcrops of trap rock intruded during Upper Cretaceous time are known in Travis, Hays, Bexar, Uvalde, Kinney, Edwards, Bandera, Kerr, and perhaps other counties in central Texas. There is a rather extensive outcrop of hypersthene olivine gabbro on the Moss ranch in the basin of Goldmine Creek, in west-central Llano County. There are a number of scattered outcrops of basic igneous rocks in the area south of the Marathon basin and east of Maravillas Creek in Brewster County. Basaltic lava outcrops extensively near Bee Cave Tank and near Maravillas Creek, in the vicinity of the Marathon-Stillwell Canyon road. There are numerous basic intrusive bodies and lava flows in the Terlingua district and southern Big Bend, also in Brewster County. The area extends into southern Presidio County. West of the Rim Rock escarpment in northwestern Presidio County numerous diabase dikes intrude the Cretaceous rocks. Basalt caps some cone-shaped hills just south of the west end of the Wylie Mountains in southern Culberson County, and it also forms the highest part of the Van Horn Mountains in the southwest corner of Culberson County. It is exposed along the highest place in the road (Wild Rose Canyon) in Limpia Canyon north of Fort Davis and also in the vicinity of San Martine, westernmost Reeves County. Some small hills of basalt rise above the sand, gravel, and silt plain south of the Malone Mountains, and there are other outcrops in the northern part of the Diablo Plateau and in Cox Mountain, 15 miles north of Eagle Flat railway station, all three being in Hudspeth County. The most important outcrop in Travis County is Pilot Knob, south of Austin.

Some trap rocks are utilized for monumental and building stones. Although expensive to crush, because of its hardness and toughness, trap rock is very resistant to abrasive wear. Because it is heavy and breaks into angular blocks which do not roll, trap rock and furnace slag, which possesses similar properties, are among the best of all materials used for railway ballast. There is a large crushing plant at Knippa station on the Southern Pacific Railroad in Uvalde County which produces railroad ballast, concrete aggregate, and road surfacing material from trap rock.

Reference

Lonsdale, J. T., Igneous rocks of the Balcones fault region of Texas: Univ. Texas Bull. 2744, 178 pp., 1927.

VOLCANIC ROCKS (LAVAS, TUFFS, AND BRECCIAS)

The basic lavas have been considered in the section on trap rock. The volcanic rocks of acidic or intermediate composition in Texas are widely distributed in every county in Trans-Pecos Texas except El Paso and Terrell. In Reeves County they occur in the southwestern border strip and in Pecos County only in the westernmost corner. They are most widespread in Jeff Davis, Presidio, and Brewster counties and in southern Hudspeth and Culberson counties, the Sierra Blanca group of peaks in Hudspeth County being the only localities of volcanic rock, north of the Texas and Pacific Railway. The main area of volcanic rocks is about 100 miles broad and extends southwards far into Mexico. However, in the southern half of the Big Bend either the Cretaceous non-volcanic rocks or post-volcanic alluvium covers half the surface. Over half of Jeff Davis County is covered by the volcanic rocks as well as an additional area of about the same size in northern Presidio and northwestern Brewster counties. Eagle Mountain in southeastern Hudspeth County is an important volcanic center.

These volcanic rocks include a great variety of stone suitable for many different constructional purposes. Some can be quarried into dimension stone almost as easily as ordinary limestone. The more acid or rhyolitic lava flows are sometimes banded and ribboned with different colors. The more coarsely fragmental rocks, known as breccias, tuff-breccias, and agglomerates, are often spotted or mottled. Some of the tuffs are highly silicified and likewise exhibit varicolored bands. Contorted flow structure rhyolite lava and tuffs with crumpled and wavy laminations of various colors in the vicinity of the china clay deposits about a mile north of the Fort Davis-Valentine road, 16 miles west of Fort Davis, have been highly altered and densely silicified by hot spring or solfataric emanations. It would be difficult to find elsewhere any more beautiful ornamental stones with a wider range of color than occur in this locality. Many of the more compact rocks can be highly polished. Some of the softer tuffs harden on exterior surfaces when exposed to the air.

Reference

Osann, C. A., Report on the rocks of Trans-Pecos Texas: Texas Geol. Surv., 4th Ann. Rept., pp. 121–138, 1893.

MINERAL AND STONE PRODUCTS

ASBESTOS

Asbestos in the strict sense is a variety of the mineral actinolite of the amphibole (hornblende) group. However, the mineral most widely used for asbestos is the chrysotile variety of serpentine. A third asbestos mineral is anthophyllite, a variety of which intermediate between it and gedrite and close to ferroanthophyllite in composition is called amosite and is extensively worked in the Transvaal of Africa. There are thus three fibrous, fireproof minerals used for asbestos.

Longer-fibred chrysotile with fibres roughly three-eighths inch or more in length is spun generally into yarn, which is woven into textile products such as brake-band linings, theater curtains, packings, and fireproof suits and gloves. Shorter grades are used for compressed sheets, asbestos paper, asbestos-cement shingles, floor tiles, and millboard. The shortest fibres are used in asbestos cement, fireproof paints, packings, and insulating materials.

The fibre of the amphibole asbestos so far produced in this country is too weak and brittle for spinning or for manufacture of asbestos paper or roofing, although special grades are used for acid filters, and other types are used for fillers and insulation. There is, however, now a marked tendency to use non-spinning grades of amphibole asbestos in molded brake bands instead of chrysotile in woven ones. The greatest such use of asbestos is for brake bands. This development is a hopeful one for the Texas deposits of amphibole asbestos, provided they are proven to occur in commercial quantity.

A short fibre or "microasbestos" is used satisfactorily in Austria in a mixture of 4 to 6 per cent in asphalt for surfacing roads. Asbestos is used for surfacing tennis courts. Uses recently developed are for building automobile bodies and for walls and partitions in fireproof "pre-fabricated" houses. Asbestos-cement pipe is used for water mains and for conveyance of various liquids and gases, especially for solutions which must be kept free from iron rust. Asbestos cloth is used for scouring and high lustre polishing. B. Marcuse[3] remarks:

> Steel rusts, wood wears and rots, and stone disintegrates, but asbestos resists the action of acids, is proof against rain, snow, all harmful influences, and defies erosion. . . . Unfortunately, the public is still in the dark regarding the merits of this wonderful mineral. Asbestos is also a perfect non-conductor of electricity, and by its use the heavy fire losses which have resulted through defective wiring may be avoided. Made into boiler and pipe coverings, it is saving hundreds of millions annually. The best engine packings and gaskets are made with asbestos. It is a splendid non-conductor of heat, cold, and sound, and is of incstimable value to all users of machinery, to manufacturers, to builders of homes, public buildings, ships, railway carriages, and motor cars. The demand for asbestos is increasing by leaps and bounds, and there are tremendous possibilities ahead of the industry.

Prices of asbestos range all the way from $8 to $450 per ton. The longer the fibre the higher is the price. Amphibole asbestos is worth up to perhaps $25 per ton. In 1932 the United States produced only 3½ per cent of its consumption. The main sources of the world's asbestos are Quebec in Canada, the Ural Mountains of Russia, and

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[3]Marcuse, B., Asbestos, *in* Spurr, J. E., and Wormser, F. E., The Marketing of Metals and Minerals, pp. 235–236, McGraw-Hill Book Company New York, 1925.

Rhodesia. The Island of Cyprus and the Transvaal have produced important amounts. Most of the present United States production comes from northern Vermont, where short fibre chrysotile is produced in the southern extension of the Quebec belt. Chrysotile has been produced in east-central Arizona (north of Globe) and mass-fibre anthophyllite is mined in Georgia.

Amphibole asbestos, in characteristics close to the tremolite end of the tremolite-actinolite isomorphous series, as determined by Dr. John T. Lonsdale, is known to occur as veins in serpentine in four different localities in Llano and Gillespie counties, Texas. The local ties are: the serpentine in the ridge west of the Llano-Oxford road on the Collins and Moss properties, the Aaron Rhode 160-acre tract near the southwest corner of Llano County, in the Crabapple Creek basin on the Holman and Ehlers ranches near the Llano-Gillespie county boundary, and in the large serpentine mass occupying the common boundary of Gillespie, Blanco, and Llano counties, mostly on the Othello Davis and Pierce Smith ranches. Fresh material obtained of late apparently indicates that at least part of the asbestos is chrysotile.

The surface outcrops are of considerable promise, especially those in the Crabapple Creek basin, but further intelligent prospecting is necessary before one can venture an opinion concerning them. The prospector should bear in mind that the veins are apt to be very irregular in direction and width and are apt to wedge out, split, bridge, or anastomose in a complicated manner. The ending of the particular vein is really no indication that the ground is worthless. The veins on the surface are quite wide and the material is cross-fibre (at right angle to the walls), the latter being unusual because chrysotile and not amphibole asbestos is generally cross fibred.

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ASPHALT ROCK

Asphalt rock in commercial quantities occurs in two localities in Texas. Asphaltic sandstone in the Basement sands of the Cretaceous near Saint Jo, Montague and Cooke counties, similar to deposits farther north across Red River in Oklahoma, has been worked to a limited extent. The asphaltic limestone of the Anacacho formation of Taylor Upper Cretaceous age extending for about 100 miles westward from near the west line of Bexar County nearly to Spofford, Kinney County, is the largest body of bituminous limestone known and probably has no rival unless it be another Cretaceous limestone in the Lebanon region of Syria. The commercial worth of the Anacacho rock is greatly enhanced because it can be used for paving or road topping merely upon pulverizing and heating, the percentage of bitumen either being sufficiently uniform in the natural state or rendered so relatively cheaply.

The Anacacho was formed as a shallow water barrier bar, reef, or beach deposit composed mainly of the broken up débris of shells known as coquina. This subsequently became partially consolidated into a relatively porous limestone. The formerly open spaces became filled with asphaltic oil deprived of the volatile constituents possessed by the usually fluid petroleum. The writer considers that the asphaltic tar was distilled out of underlying bituminous sediments by the heat generated by the basic igneous intrusions (diabases or dolerites) common in this section of the Balcones fault zone. In Uvalde County some of the igneous rocks are of intermediate composition (phonolites).

The beds now exploited range from 10 to 50 feet in thickness and lie in a syncline in close association with the igneous rocks. The content of asphalt in them varies from 9 to 12 per cent. The fresh rock is dark gray in color, weathering quickly on the surface to a bluish to grayish white. The productive strata are underlain and overlain by limestone with less asphalt content or with little or none.

The rock is quarried by the bench method. The quarries are in the southwest corner of Uvalde County, the loading points being Blewitt, Dabney, and White, on spurs from the Southern Pacific and Missouri Pacific railroads. The producing companies are the Uvalde Rock Asphalt Company, 510 Frost National Bank Building, San Antonio, with quarries near Blewitt; Texas Rock Asphalt Company, 928 North Flores Street, San Antonio, quarry at Dabney; and White's Uvalde Mines, 1901–9 Alamo National Bank Building, San Antonio, with quarry at White, 10 miles southeast of Cline station on the Southern Pacific Railroad. These companies in the year 1932 sold 132,636 tons, valued at $312,663. In 1929 they shipped 320,931 tons. Kentucky ranks second to Texas in production. Small quantities are produced in Alabama, California, Kansas, Missouri, Oklahoma, and New Mexico, although the production outside of Texas is practically all asphaltic sandstone, the largest amounts of which occur in California and 6 miles and more north of Santa Rosa, New Mexico.

An asphaltic sandstone in the Pulliam formation, of Navarro Cretaceous age, extends from the fault at Black Waxy Falls to another fault at least 3 miles downstream on Nueces River in the vicinity of the Uvalde-Zavala county line. It is 5 feet thick and has an average asphaltic content of 12 per cent. It is overlain by 10 feet of sandstone with a lesser percentage of asphalt.

The asphaltic sandstone of Montague and Cooke counties lies at or near the top of the Trinity sand, just under the thin Goodland limestone. The asphalt was most likely, though not certainly, derived from oil which seeped out of the underlying folded and faulted rocks, which can be seen now to seep oil in the south flank area of the Arbuckle Mountains on Oil Creek near Marietta, Love County, Oklahoma, and also farther north. The sandstone is impregnated with asphalt for an average thickness of from 3 to 4 feet, the average content of asphalt in the rock being about 10 per cent.

An asphaltic limestone of Trinity Cretaceous age outcrops in the vicinity of Burnet, Burnet County. Other asphaltic sandstones, oil sands, or live seepages are known as follows: in the Permian, Coke County; in Cretaceous at 15 miles northeast of Fort Stockton, Pecos County; in Pennsylvanian at Crystal Falls on Brazos River, Stephens County; in Claiborne Eocene at localities from 10 to 12½ miles northeast of Palestine, Anderson County, and on Oil Creek near

Chireno, Nacogdoches County; and in Jackson Eocene east and northeast of the town of Rockland in and near the northwest corner of Jasper County (old Tar well, Boykin Springs, and spring on Miller League). A pit of asphaltic tar formerly existed in the swamp overlying the salt dome at Sour Lake, Hardin County, which contained bones of Pleistocene mammals described by Joseph Leidy.[4] This was the second occurrence of fossil vertebrates described from Texas.

Aside from paving and road-making, the Uvalde rock asphalt has been used for roofing and floor tiles. Asphalt produced as a residue in petroleum refining competes with the natural or rock asphalt, the Texas oil refineries producing 143,900 tons in 1932. The uses of asphalt as given by Redfield[5] are as follows:

Paving asphalt.—Refined asphalt and asphaltic cement, fluxed and unfluxed, produced for direct use in the construction of sheet asphalt, asphaltic concrete, asphalt macadam, and asphalt block pavements, and also for use as joint filler in brick, block, and monolithic pavements.

Roofing asphalt.—Asphalt and asphaltic cement used to waterproof and dampproof tunnels, foundations of building, retaining walls, bridges, culverts, etc., and for constructing built-up roofs.

Briquetting asphalt.—Asphalt and asphaltic cement used to bind coal dust or coke breeze into briquets.

Mastic and mastic cake.—Asphalt and asphaltic cement for laying foot pavements and floors, waterproofing bridges, lining reservoirs and tanks, capable of being poured and smoothed by hand-troweling.

Pipe coatings.—Asphalt and asphaltic cement used to protect metal pipes from corrosion.

Molding compounds.—Asphalts used in the preparation of molding compositions, such as battery boxes, electrical fittings, push buttons, knobs, handles, and other equipment.

Miscellaneous uses.—Asphalts and asphaltic cement used as dips and in the manufacture of acid-resisting compounds, putty, saturated building paper, fiber board, and floor coverings; and not included in the preceding definitions.

Flux.—Liquid asphaltic material used in softening native asphalt or solid asphalt for paving, roofing, waterproofing, and other purposes.

Cut-back asphalts.—Asphalts softened or liquefied by mixing them with petroleum distillates.

Emulsified asphalts and fluxes.—Asphalts and fluxes emulsified with water for cold-patching, road laying, and other purposes.

Other liquid products.—Petroleum asphalt, exclusive of fuel oil used for heating purposes, not included in the preceding definitions.

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[4]Leidy, Joseph, Notice of some vertebrate remains from Harden (Hardin) County, Texas: Acad. Nat Sci. Philadelphia. Proc. 1868, pp. 174-176, 1868.

[5]Redfiield, A. H., Asphalt and related bitumens: U. S. Bur. Mines, Minerals Yearbook 1932–33, p. 559, 1933.

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FOUNDRY OR MOLDING SAND

A silica sand to which some bonding material, usually fire clay or some organic substance such as molasses or flour, has been added serves as a foundry or molding sand. Molding sand must be highly refractory and be sufficiently coherent and yet porous enough to permit the escape of gases from the metal castings. The sand may be neither too angular nor too round. Size of sand grain depends upon the size of the casting. Ordinarily the sand used for steel casting should have a silica content of 97 per cent or more with well rounded grains graded between 20 and 100 mesh with average fineness of 35 to 48 mesh. Entirely different types of sand are needed for the casting of brass, aluminum, and steel. Those used for iron casting commonly contain 75 to 85 per cent silica, 5 to 13 per cent alumina, less than 5 per cent of iron oxide, rarely more than 4 per cent of combined water, and usually less than 2½ per cent of lime and magnesia. Sand for brass molding may have higher percentages of iron and lime. A core sand as a rule should be high in silica and low in alumina.

Comparatively little molding sand is now used in Texas because the foundry industry is little developed. There can be no doubt that Texas possesses materials adequate for all types of molding sands. Glacial lake deposits near Albany, New York, produce much, but there are many local sources near various manufacturing centers in the northeastern quarter of the United States. The production widely fluctuates with manufacturing activity, ranging in the last five years from 1,000,000 to 6,000,000 tons. The average value is approximately $1 per ton.

Tests on molding sands.—Tests of Texas sands have been made at Cornell University. The sand samples were collected by the Bureau of Economic Geology and shipped to the Cornell laboratory, the testing having been carried on in coöperation between the Department of Geology of Cornell University, the American Foundrymen's Association, and the Bureau of Economic Geology.

Following is a record of the samples giving locality and comments for each, the samples being entered according to laboratory numbers.

1640. Fort Worth, Tarrant County. This sample represents the finest grade of sand obtained by screening. From pit at Fort Worth.

Comment: A very coarse core sand.

1641. Texas Builders Supply Company, molding sand, from pit located 1 mile west of Liberty, Liberty County. It connects with the main line of the Southern Pacific Railroad by means of a switch. Formation: river deposit. The molding sand ranges from 1½ to 2½ feet in thickness and underlies probably 23 acres. There is about 1 foot overburden. It is used for heavy castings.

Comment: Molding sand; good strength but moderate permeability.

1642. W. D. Hayden Company, steel sand, dredged from San Jacinto River near Lynchburg, Liberty County. Covers river bed for several miles, with a varying thickness of from a few feet up to 15 feet.

Comment: Core sand but a rather coarse one.

1643. From Cantu farm, 14.5 miles southeast of San Antonio, Bexar County, on San Antonio-Cuero highway and 1½ miles from the Southern Pacific Railroad. Formation: Wilcox division of Eocene. Deposit underlies 50 acres. The sample represents an average of several beds, some of which are more clayey than the others.

Comment: Molding sand. Good strength but low permeability, unless considerable water added, *viz.*, 12.4. This may be too much water for good working conditions. Rather high in clay.

1644. Fort Worth Sand and Gravel Company, Fort Worth, Tarrant County. Formation: river deposit. Covers about 12 acres and ranges from 1 to 3 feet in thickness.

Comment: Molding sand. Good strength, not high permeability. Would have to be opened up with a more open sand.

1645. J. E. Espey sand pit, 22 miles south of San Antonio, Bexar County. Formation: Wilcox division of Eocene. Deposit averages 7 to 11 feet in thickness. The overburden is loose sand 2½ to 3 feet thick.

Comment: Molding sand. Good strength and good permeability. Probably best of the whole series sent.

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GLASS SAND

Glass sand is the major constituent in glass, forming from 52 to 65 per cent of the original mixture. High grade glass sands are over 99 per cent silica (SiO_2). They should be nearly white in color, or colorless, and of medium fineness (20 to 50 mesh) with grains of uniform size and preferably even and angular. The highest grades are crushed, washed, dried, and screened. The most exacting and important specification is the purity of the material. For optical crystal and lead-flint glass the percentage of iron oxide (reckoned as Fe_2O_3) must not be more than one-twentieth of 1 per cent. For ordinary plate glass it may be as high as one-fifth of 1 per cent and for mirrors one-tenth of 1 per cent. In window glass the iron oxide should not exceed one-half of 1 per cent, but for ordinary green bottles it may run as high as 7 per cent. Calcium and magnesium oxides in small amounts are not objectionable if uniformly disseminated. The presence of alumina (Al_2O_3) is permissible in sand for some kinds of glass. For flint glass the alumina content should not run over one-tenth of 1 per cent and for plate or window glass not over six-tenths of 1 per cent. Percentages of iron oxide up to as high as one-fifth of 1 per cent can be neutralized by using a decolorizer such as manganese, cobalt, selenium, or nickel. Magnesia (MgO) is considered by some as undesirable because it raises the melting point of the batch.

There are probably none of the highest grade glass sands in Texas although there is considerable vein quartz in the pre-Cambrian rocks in Llano, Burnet, and Mason counties in central Texas which can be used for quartz, lead-flint, crystal, and optical glass. The Caballos novaculite of the Marathon basin, Brewster County, if care is used in selecting sufficiently pure material, can be used for window glass. For a market within the El Paso trade territory, it would probably be cheaper to crush the novaculite than to pay transportation charges on window glass or glass sand produced elsewhere.

For ordinary bottles and jars the Basement sands of the Cretaceous at Santa Anna, Coleman County, and the Carrizo sands of the Claiborne Eocene of the Atascosa-Bexar-Wilson counties district have been used. These two formations present possibilities in other areas of their outcrop, although usually the percentage of iron has proven to be too great.

GRAPHITE

Graphite is carbon or carbon with impurities. It occurs in the form of flakes or small foliated masses, lumps, and in an impure earthy form. Rarely it is found in six-sided tabular crystals. It is black, soft, and greasy in appearance. A rock containing graphite when rubbed becomes shiny at the surface and the mineral, being soft, stains the hands. It is not uncommonly a constituent of schists derived from sedimentary rocks. Under these conditions it is believed to have formed from the organic material of the original rock. Coal beds are at some localities changed to graphite. To a limited extent graphite occurs in altered limestones, in veins, in granite, and in meteorites.

In the market graphite is known as crystalline and amorphous. The crystalline graphite occurs in veins or lumps and disseminated in the rocks, in which condition it is known as flake graphite. That found in schists is very largely or entirely crystalline. Even the so-called amorphous graphite is minutely crystalline or cryptocrystalline. The crystalline graphite usually commands the higher price. Artificial graphite is made in electric furnaces from anthracite or from petroleum coke. Most of it is made into electrodes, although it is used also in dry batteries. Aside from these uses it comes into competition with the cheaper grades of graphite including the amorphous variety and graphite dust.

Graphite, having good electric conductivity, resistance to acid and to high temperatures, finds many uses in the industries. Until recently the largest single use, 50 per cent or thereabouts, was in the manufacture of crucibles. This usage, however, has declined to 15 per cent or less owing to changes in melting steel and brass, electric and gas-fired hearth furnaces now being used.[6] Another very large use of graphite developed in recent years is in manufacture of dry batteries particularly for radio purposes. This demand, however, has declined since batteries for radio have been largely dispensed with, radios being connected with electric power systems. An important use for cheaper grades of graphite is for foundry facings which now consumes approximately 50 per cent of domestic production.[7] Another use of graphite is in lubricants for which purpose it is usually mixed with oils. Low grade graphite is used in making paint. Other uses are in manufacture of "lead" pencils, coating for boilers, graphite electrodes, electrotyping, stove polish, automobile generator brushes, shoe polish, and fertilizer filler.

The world production of graphite in 1928 was probably above 150,000 short tons. Of this amount the production in the United States was 5611 tons of which 2994 tons were amorphous and 2617

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[6]Tyler, P. M. Graphite: U. S. Bur. Mines, Inf. Circ. 6118, p. 27, 1929.

[7]*Idem.*

tons crystalline.[8] The graphite used in the United States approximates 20,000 short tons annually. The imports making up the large difference between the amount produced and the amount used are chiefly from Mexico, Ceylon, Canada, Madagascar and Korea, with smaller amounts from several other countries. The price of crystalline graphite at the mine varied in 1928 from 1.5 to 5.8 cents per pound depending upon grade, the average being 4.8 cents.[9]

Notwithstanding that production is much less than amount used, the difference being supplied by imports, there is some graphite exported. The exported product is largely finely powdered and prepared for pencils. Much, perhaps most, of the export is Mexican graphite refined in this country. Smaller amounts are exported for other purposes as for use in paints, lubricants, commutator brushes, and dry cells.

A tariff is placed on imported graphite. The tariff is heaviest on crystalline flake and least on amorphous. From 1922, when the tariff was established, the duty on imported crystalline flake has been 1½ cents per pound; on crystalline lump chip or dirt, 20 per cent ad valorem; and on amorphous, 40 per cent ad valorem.

Graphite is found in Texas in the pre-Cambrian formations, the Packsaddle schist of the Central Mineral region, and to a lesser extent in the Carrizo schists of the Van Horn region. Graphite-bearing schists in the Central Mineral region have been observed and more or less prospected in several localities. South of the Southern Pacific Railroad west of Little Llano River and 1⅞ miles south of Lone Grove in Llano County is a locality where graphite schists have been somewhat mined. This belt of graphite schists is found on both sides of the river and can be followed in a northwesterly trend until lost under overlying Cambrian sandstone.[10] Another belt of graphite schists is reported 2 miles south of Llano. This belt also trends in a northwesterly direction.

Graphite was formerly mined by the Southwestern Consolidated Graphite Company on Clear Creek 9 miles west of Burnet, Burnet County. The graphite is found here as a stratum of graphitic schist

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[8]Middleton, Jefferson, Graphite: U. S. Bur. Mines, Mineral Resources of the United States, 1928, Part II, Nonmetals, p. 81, 1930. The ton used in statistics on graphite is the short ton of 2000 pounds.

[9]*Ibid.*, p. 83.

[10]Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: U. S. Geol. Surv., Bull. 450, p. 78, 1911.

from 75 to 150 feet thick and of undetermined downward extent. At either side of the graphite schists are mica schists, and both are cut by dikes. The graphite schist stratum trends northeast-southwest and has been located on this property by surface exposure and borings through an extent of 4500 feet. Two and a half or 3 miles farther to the north a plant was opened in 1928 by the Burnet-Texas Company and temporarily worked in what is apparently the same stratum.

This plant of the Southwestern Consolidated Graphite Company, established in 1916 or 1917, was burned in March, 1927. A new modern plant was built in which the oil-froth flotation method was used for recovery of graphite. The plant was equipped with an electrostatic unit which, however, was but little used since the grades of graphite required by the market are obtained by the flotation process. The plant is not now in operation.

The schist strata at this locality dip at a high angle approaching vertical, and mining was carried on from the surface exposure downward. The uppermost few feet of the schist at the surface are decomposed and discolored by oxidation. However, the surface as well as the deeper ore was milled, no overburden being removed. Working was by the open pit method from the surface downward. The pits are nearly dry, comparatively little water other than rainfall coming in. The more abundant minerals of the schist are quartz, flake graphite, a limited amount of mica, and, in the unoxidized schist, pyrite, and perhaps other sulphides. The ore varies in richness but will probably average 5 or 6 per cent graphite.

Graphite is found in many countries. The following brief notes refer to the more important producing regions. Lump crystalline graphite is found in large quantities in Ceylon where it occurs in veins varying from one inch to several feet in width. In Madagascar flake crystalline graphite occurs widely in schists and gneiss. The graphite-bearing strata are 30 to 65 feet in thickness and may be followed at their outcropping margins for long distances. The graphite ore averages 10 to 12 per cent, although rich ore may be as much as 50 to 80 per cent graphite. The principal associated minerals are quartz and mica. The standard refined product is 85 per cent carbon. The reserves in Madagascar are large.[11]

[11]Tyler, P. M., Graphite, Part II, Domestic and foreign deposits: U. S. Bur. Mines, Inf. Circ. 6122, 25 pp., 1929.

Amorphous graphite is found in large quantities in Mexico, near Hermosillo, Sonora, about 350 miles from the Mexican border. The graphite is from coal beds. There are several beds of which the thickest is said to be 9 or 10 feet on an average although, as a result of folding and squeezing, it may be as much as 24 feet thick. The strata alternating with the graphite are chiefly sandstones, the whole being near intruded granites. The graphite may contain as much as 95 per cent carbon although an average is 86 per cent or thereabouts. A small percentage of silica, alumina, and iron is present.

Austria produces much low grade amorphous graphite. In the Alps of Styria the graphite is altered coal which occurs in beds up to 30 feet thick and grades into anthracite. The strata alternating with the graphite are slates and limestones. The graphite runs 40 to 95 per cent carbon. In lower Austria amorphous graphite occurs in strata between mica schist and gneiss.

Bohemia produces graphite chiefly amorphous and of low grade. The deposits are graphite schists. In Italy amorphous graphite grading into anthracite occurs in beds up to 10 feet thick. Korea produces considerable graphite, most of which is amorphous and of low grade.

In the United States amorphous graphite is or has been produced in several states. The principal producing states are Nevada and Wisconsin, although amorphous graphite is mined or reported from several other states.

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MINERAL WOOL

Mineral wool is made from a marl, clay, or shale which contains a sufficient percentage of calcium carbonate to permit it to fuse at a relatively low temperature. While in the molten state it is blown out by means of jets of steam into minute glass tubes having a small bulb at one end. Air confined in the interior of the tube is a non-conductor of heat and cold, and the product is coming to be used extensively for fireproof building insulation.

Mineral wool is made at Wabash and Alexandria, Indiana. The shale (called "fuzz rock" by the quarrymen) is mixed with a small percentage of flux rock (generally limestone or magnesian limestone). The following analysis indicates the composition of the shale and flux rock used in Indiana:

Constituent	Shale *Per cent*	Flux Rock *Per cent*
Calcium carbonate ($CaCO_3$)	28.39	50.89
Magnesium carbonate ($MgCO_3$)	13.00	40.72
Silica (SiO_2)	30.28	7.94
Alumina (Al_2O_3)	14.07	0.72
Ferric oxide (Fe_2O_3)	5.80	
Titaniun oxide (T_2O_2)	0.73	
Loss on ignition other than CO_2	6.61	
	98.88	100.27

Ordinarily the alumina (Al_2O_3), iron (Fe_2O_3), and silica (SiO_2) content about equals the lime (CaO) and magnesia (MgO) content but does not have to do so. The calcium oxide (CaO) content must be not less than 20 nor more than 30 per cent.

The process of manufacture by the Union Fibre Company, Wabash, Indiana, is stated by Cumings and Shrock to be as follows: "The crushed rock is charged in cupolas with the best grade of foundry coke and melted at a temperature of about 3800° Fahrenheit. The molten rock coming from the cupola is blown by means of a steam jet into the wool chamber, falling therein as a light, fibrous, wool-like material of about 12 times the bulk of the original rock."

Some of the uses of mineral wool are the following:

Insulating refrigerators and coolers
Packing acid carboys for shipment
Insulating underground pipes of all kinds
Filtering acid mist from sulphur dioxide gas
Filtering sulphur dioxide and trioxide

Sound deadening of partitions and floors
Packing walls and floors to prevent entrance of rats, mice, and insects
Insulating pipe lines carrying melted sulphur and super-heated water
Insulating tanks, fireless cookers, stoves, ovens, and furnaces
Building insulation

Marls and calcareous clays and shales suitable for the manufacture of mineral wool occur in the Cretaceous rocks of Texas in localities near most of the large centers of population. One of these is the Del Rio clay, as, for example, 3 miles northwest of the center of Austin. The Taylor marl, where of the requisite composition, is likewise suitable, and some of the more calcareous Eagle Ford shale is perhaps utilizable also.

Clays of suitable composition to make mineral wool without the addition of other ingredients are known to occur in large deposits in the near vicinity of Dallas, Fort Worth, Waco, Temple, Taylor, Austin, New Braunfels, San Antonio, El Paso, and Amarillo. Altered volcanic ash with a sufficiently high percentage of fluxing materials to produce the product occur in large deposits in Fayette, Grimes, Brazos, and possibly other counties within about 80 miles of Houston. All these deposits can be worked by drag-line, power shovels or plows and scrapers and with the utilization of gas, crude oil, or possibly electricity for fuel instead of coke in a continuously-operating furnace the cost of production should be lower than that of the present operations in Indiana. A relatively small investment probably will suffice for a plant installation and the presence of suitable crude material so near the various populous centers is conducive to the development of small local plants saving high transportation costs and breakage to which the material is subject when transported long distances. Central Texas has plentiful supplies of siliceous limestone which can be mixed with clay and coke in the present type of cupola furnace used in the industry but it is hoped and thought that the materials first mentioned can be utilized at less expense.*

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*For additional information on mineral wool, see paper by M. M. Leighton, "Mineral wool and methods of manufacture," Univ. Texas Bull. 3501, 1935.

ABRASIVES, GRINDING STONES, AND POLISHERS

Under the heading abrasives, grinding stones, and polishers is included a group of materials, many of which have in addition other uses. Among these materials are diatomaceous earth, novaculite, quartz, sandstone and sand, tripoli, and volcanic ash. Other abrasive materials not separately treated in this paper are garnet, emery, talc, pumice, and pumicite.

Natural abrasive products have been widely supplanted by synthetic silicon carbide (carborundum) and aluminum oxide (alundum) made possible by cheap hydroelectric power. These artificial products are harder than quartz and garnet and rival corundum (emery). They can be bonded and manufactured into many special types of grinding equipment suitable to the precise requirements of the manufacturer and can be produced in almost any size of grain or cutting speed. These artificial abrasives are also being used as refractory material, floor tile, and stair treads. Steel balls chilled or hardened by heat treatment or alloys are supplanting quartz and chert pebbles and, in small sizes, are a substitute for black diamonds (bort or carbonado) in rock drills and stone-cutters. The market continues to expand for the artificial abrasives and the natural siliceous products, but natural whetstones and grindstones suffer from not only diminished demand as old uses and processes are supplanted by new but also from increased competition of synthetic products.

DIATOMACEOUS EARTH

Diatomite or diatomaceous earth occurs in beds in the Blanco middle Pliocene formation of Crosby County, Texas. Because it must be detected by examination with a compound microscope and, therefore, is difficult to find, it is often overlooked, and it is probable that a number of other deposits will be found in Texas especially, perhaps, in the volcanics of Trans-Pecos Texas, where it would resemble closely very fine-grained volcanic ash or tuff. Another possible place of occurrence is in or near the volcanic ash zones in the Eocene (especially the Jackson) and Catahoula and Fleming (Oakville-Lagarto) formations which extend across the Gulf Coastal Plain and contain many pond and lake deposits. It has been reported in small quantity under the volcanic ash in Kent County.

The known Crosby County occurrences are at a locality 1 mile south of Mount Blanco and at a second locality 23 miles southeast of Mount Blanco, near the foot of the plains. At the former locality there are two beds, the lower 8 feet thick and separated from the upper bed, 4 feet thick, by 20 feet of pack sand. At the second locality a lower bed 4 feet thick is separated by 3 feet of purple clay from the upper bed which is 3 feet thick.[12]

Diatomite is composed of the siliceous tests of the microscopic plants known as diatoms. Not less than 40,000,000 tests of diatoms are necessary to form one cubic inch of diatomaceous earth, and yet on the east flank of the Temblor Range in California the thickness of the Monterey Miocene diatomaceous earth may be as great as 7000 feet. Diatoms live both in sea water and in fresh-water ponds and lakes.

The three chief uses for diatomite are in the refining of sugar, in insulating material, and as a filler in battery boxes. It is also known as infusorial earth or kieselguhr. It is fine and uniform in texture, light in weight, high in porosity, and is relatively inert chemically. Dry lump material weighs about 28 pounds per cubic foot (less than half that of water), and dry loose powder will weigh from 7 to 16 pounds per cubic foot. When carefully pulverized and graded, it is used as a filter or as a clarifying and decolorizing agent like fuller's earth. Relatively minor amounts are used as an abrasive for polishing metals, glass, and furniture; and also in enamel and in cosmetics. It is used abroad as an absorbent of nitroglycerine, forming dynamite. Some has been used in concrete.

Diatomite is widely distributed, but most of the production comes from marine deposits in the southern Coast Ranges of California. Oregon, Washington, Idaho, Nevada, New York, Virginia, and Maryland are other producing states. Extensive lake deposits of diatomite occur near Benson and Safford in southern Arizona. Production in the last three years has averaged about 80,000 tons, valued at $1,300,000 annually.

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[12]Cummins, W. F., Report on the geography, topography, and geology of the Llano Estacado or Staked Plains with notes on the geology of the country west of the plains: Texas Geol. Surv., 3rd Ann. Rept., pp. 143-144, 1892.

NOVACULITE

Novaculite is a variety of white chert used for oilstones and whetstones suitable for producing a fine cutting edge on the better grade of tools. It is a rare rock known only in southeastern Oklahoma, southwestern Arkansas, and the Marathon basin of northern Brewster County, Trans-Pecos Texas. It is quarried in the vicinity of Hot Springs, Arkansas, and shipped to near the Canadian line in New Hampshire, where the finished whetstones are made.

Microscopic study shows that novaculite is mainly or altogether a crystalline aggregate of interlocking granules of quartz, forming a very fine-grained mosaic. It contains less alkali-soluble silica than does ordinary chert or flint and practically no water, indicating the almost complete absence of hydrous silica. The writer suggests that novaculite may be a "metamorphosed" chert which has been recrystallized with contemporaneous loss of water.

Although the white novaculite and associated cherts at Marathon contain skeletons of Radiolaria, the source of so great a quantity of pure silica without admixture of or interbedding with other substances as we find in the novaculite formation is difficult to explain. There is some possibility that at least most of it came from the denudation of the unconformably underlying Maravillas chert, weathered by leaching to tripoli, and re-deposited in the basin in which the novaculite accumulated.

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QUARTZ

Quartz is silica (SiO_2). It is used in making fused-quartz glass (such as "pyrex") and ferrosilicon, as a flux in some metallurgical processes, as packing in acid towers and water-filters, as a refractory, a filler, for sandpaper, scouring soaps and compounds, metal polish, and safety matches, in the manufacture of white ware and enamels. Exceptionally clear crystals are used in optical instruments and the electrical industry. Some clear, transparent, and colorless quartz is cut as brilliants (Hot Springs diamonds) for cheap jewelry.

The principal uses of silica are tabulated by R. B. Ladoo[13] as follows:

Uses of Silica	Types of Silica Used
Abrasive uses:	
In scouring and polishing soaps and powders	Quartz, quartzite, flint, chert, sandstone, sand, tripoli, and diatomaceous earth; all in finely ground state
In sandpaper	Quartz, quartzite, flint, sandstone, and sand; coarsely ground and closely sized
In sand-blast work	Quartz, quartzite, sandstone and sand, crushed into sharp angular grains uniform in size
Metal buffing, burnishing and polishing	Ground tripoli and other forms of ground silica
For sawing and polishing marble, granite, etc.	Sharp, clean sand graded into various sizes
As whetstones, grindstones, buhrstones, pulpstones, oilstones, etc.	Massive sandstone from very fine- to moderately coarse-grained
Tube-mill lining	Chert, flint and quartzite in dense, solid blocks
Lithographers' graining sand	Medium to fine sand or rather coarsely ground silica and tripoli
Tube-mill grinding pebbles	Rounded flint pebbles
In tooth powders and pastes	Various forms of pure silica finely ground
Wood polishing and finishing	All forms of silica ground to medium fineness
Refractory uses:	
In making silica fire brick and other refractories	Fairly pure quartzite known as gannister; not less than 95 per cent SiO_2 nor more than 0.40 per cent alkalies, tightly interlocking grains desired
Metallurgical uses:	
In making silicon, ferrosilicon and silicon alloys of other metals, such as copper	Moderately pure sand, massive crystalline quartz, sandstone, quartzite or chert
As a flux in smelting basic ores	Massive quartz and quartzite
Foundry-mold wash	Ground sandstone, quartz, and tripoli

[13]Ladoo, R. B., Non-Metallic Minerals, pp. 525-526. McGraw-Hill Book Company, New York, 1925.

Uses of Silica	Types of Silica Used
Foundry parting sand	Fine sand and ground tripoli
Chemical industries:	
As a lining for acid towers	Massive quartz or quartzite
As a filtering medium	Massive diatomaceous earth and tripoli, sand, finely granular quartz or quartzite, finely ground tripoli, diatomaceous earth and other forms of silica
In the manufacture of sodium silicate	Pure pulverized quartz sand, pure tripoli and diatomaceous earth
In the manufacture of carborundum	Pure quartz sand
Paint:	
As an inert extender	Finely ground crystalline quartz, quartzite and flint, also finely ground sandstone, sand and tripoli
Mineral fillers:	
As a wood filler	Finely ground crystalline quartz, quartzite, flint, tripoli and other types of ground silica
In fertilizers	Finely ground silica of all types
In insecticides	
As a filler in rubber, hard rubber, pressed and molded goods, phonograph records, etc.	
In road asphalt surfacing mixtures	
Ceramic uses:	
In the pottery industry as an ingredient of bodies and glazes	Flint, tripoli and chert, and other amorphous silica preferred; also all other forms of very pure silica, all finely ground
In the manufacture of ordinary glass	Pure quartz sand
In the manufacture of fused-quartz chemical apparatus, such as tubes, crucibles and dishes	Very pure massive quartz preferred
Decorative materials:	
In the manufacture of gems, crystal balls, table tops, vases, statues, etc.	Rock crystal, amethyst, rose quartz, citrine quartz, smoky quartz, chrysoprase, agate, chalcedony, opal, onyx, sardonyx, jasper, etc.
Insulation:	
Heat insulation for pipes, boilers, furnaces, kilns, etc.	Massive and ground diatomaceous earth
Sound insulation in walls, between floors, etc.	Massive and ground diatomaceous earth

Uses of Silica	Types of Silica Used
Structural materials:	
Sand-lime brick	Moderately pure, sharp, angular sand, preferably finer than 20-mesh, together with a small percentage of finely pulverized silica
Optical quartz:	
For the manufacture of lenses and accessories for optical apparatus	Clear, colorless, flawless rock crystal or massive crystallized quartz

Further details on the uses and properties of various forms of silica are given by F. E. Wormser.[14]

Flint or chert is a variety of quartz with a glassy lustre and no visible structure, its component crystals being too small to be seen except under fairly high magnification.

Quartz is abundant in the veins and pegmatite dikes in the pre-Cambrian rocks of the Llano uplift of Llano, Mason, Burnet, Gillespie, and Blanco counties and of the Van Horn uplift of southern Hudspeth and Culberson counties. Chert or flint in disintegrated particles is very abundant in the Marathon basin of Brewster County, where it is derived from the Maravillas chert and the Caballos novaculite, and also in certain horizons of the Ellenburger group in the Llano uplift, being widespread in southern San Saba County. Some of it—the so-called "drusy" chert—is incrusted with small quartz crystals. Flint pebbles and boulders are especially abundant in the belt of counties situated at the south foot of the Balcones escarpment, extending from Williamson County on the east to Val Verde County on the west. These occur both as upland and as valley deposits, their source being the Edwards Cretaceous formation of the Edwards Plateau.

SANDSTONE AND SAND AS ABRASIVES

Sandstone is used as whetstones (oilstones) and various types of grindstones, pulpstones, and millstones, all of which have been largely supplanted by new processes and artificial substitutes. Considerable sandstone is ground for glass and other special silica sands, the latter being used widely in ceramics, as a silica wash for molds in foundries, as a filler in roofing, paint, and other products, in fertilizers, and as abrasive in various cleaning and scouring mixtures.

[14]Wormser, F. E., Silica, *in* Spurr, J. E., and Wormser, F. E., The Marketing of Metals and Minerals, pp. 517–523, McGraw-Hill Book Company, New York, 1925.

Much sand is used in glass and as molding sand and for grinding and polishing. The Vermont marble industry uses for cutting, grinding, and polishing about one-third as much sand as it does marble. Loose sand is also ground (pulverized), being used for the same purposes as ground sandstone.

Although sand is common in most parts of Texas, sandstone suitable for stone abrasives is apparently rare east of Pecos River. An apparently excellent sandstone for an abrasive occurs in the Smithwick formation of Pennsylvanian age, between Smithwick and Marble Falls in southeastern Burnet County. In Trans-Pecos Texas the Lanoria quartzite and the Bliss sandstone in the Franklin Mountains, north of El Paso; the Carboniferous Tesnus and Haymond sandstones of the Marathon basin, Brewster County; the Permian Alta sandstones of upper Cibolo Creek basin north of Shafter, Presidio County; possibly some of the sandstones and siliceous shales of the Permian Delaware Mountain and Word formations of the Delaware and Glass mountains; and the Cretaceous Trinity (Cox, Campagrande, Etholen, and Maxon), Fredericksburg (Walnut), and Washita (Del Rio) sandstones are suitable for abrasives.

TRIPOLI

Tripoli occurs in the southwest part of and also some distance south of the town of Lampasas. It appears to be a residue from the leaching out of the calcium carbonate from the highly siliceous Marble Falls limestone of early Pennsylvanian age, leaving as a practically pure concentration the silica of abundant sponge spicules, or else the tripoli is mostly a greatly decomposed chert. Tripoli is used largely for filters, or for abrasive powders or flour, and for partings for molds (foundry facings). Because it is absorbent it is used as a washing powder in scouring soaps or as metal polishes. It is used for wood filler in paint; as a filler in rubber, particularly hard rubber; in refractory cements; and in ceramics and glass. Its absorbing power also finds use as a fuller's earth in petroleum refining. Ordinarily the total United States production, some of which is exported, varies from 15,000 to 25,000 tons annually, the crude material selling for $5 to $8 per ton, and ground from $16 to $40, depending upon the fineness of grade. Its use is now being promoted as an admixture in concrete construction. Oklahoma, Missouri, Illinois, and Tennessee are the producing states; most of the product is used east of the Mississippi.

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VOLCANIC ASH

Volcanic ash is a form of rock deposit composed of small, sharp, angular grains of volcanic glass, forming ordinary sedimentary beds. Other names applied to volcanic ash or its varieties are volcanic dust, volcanic tuff, and pumicite. Volcanic dust is volcanic ash of fine texture. Volcanic tuff is a term usually applied to the older, more or less compacted, deposits of volcanic ash. Pumicite is a more or less finely divided powder or dust made up of small, sharp, angular grains of volcanic glass of about the same composition as pumice. The terms pumicite and volcanic ash practically mean the same thing. Pumice, often associated with volcanic ash, is a highly vesicular or cellular, glassy volcanic lava, usually rhyolitic in composition. Fragments of pumice, of various sizes, and of more compact lavas as well, are often deposited with volcanic ash. Volcanic ash may have various other impurities, such as clay, sand, gravel or boulders. It is often cemented to a more or less hard, dense mass by calcium carbonate, iron oxide, or silica. It is sometimes altered through the action of hot vapors or hot waters. Cold waters also alter it greatly and probably cause its change to bentonite, although it is also possible that hot mineralized waters or vapors sometimes form bentonite from volcanic ash.

Volcanic ash is formed by the violent and explosive action of volcanoes, which throw it out in great clouds. Its eruption is accompanied by the emission of great quantities of steam and other gases. Sometimes there is so much steam or hot water accompanying the ash that great semi-liquid mud flows rush rapidly down the slopes of the volcano, overwhelming and destroying everything in their path. The acidic or more viscuous volcanic rocks, which melt at higher temperatures, form most of the ash, but more basic rocks, such as basalt, at times form large deposits.

No doubt the ash is partly formed by the comminution of rocks and crystals by friction during the explosion, but a great part of it represents lava blown out from the volcanic vent in liquid form and solidified almost instantaneously in the air. It doubtless solidifies as glass but may be subsequently devitrified, that is, crystallized into the various minerals characteristic of volcanic rocks. These crystals are generally very minute and can be seen only under the microscope.

The particles of volcanic ash may be shreds, or very angular, conchoidally-fractured flakes with the sharp edges of broken or ground glass, or may be long tubes or fibres. All these particles are often hollow and originally contained bubbles of steam or other gas. In fact, the expansion or explosion of the bubbles of gas causes a great deal of the shattering found in the glass particles. The coarser particles may be droplike, with a central cavity or vesicle. The glass particles are either colorless and transparent or have a brown tint; subsequent alteration may, however, produce other colors. Most deposits of pure volcanic ash have a whitish or light-gray color. Pure (unaltered) volcanic ash has a gritty feel when rubbed between the fingers and does not adhere like clay.

Ash from volcanic explosions is sometimes transmitted long distances through the air. That from Aleutian Islands volcanoes has at times fallen as far away as Portland, Oregon, and the fine dust-like particles from the great explosion of Krakatoa, in the Straits of Sunda, East Indies, projected into the upper atmosphere, travelled three times around the earth, and settled in some quantity everywhere along its path. Consequently volcanic ash beds may be found hundreds or even a thousand miles from their volcanic source. Fairly thick ash beds, quite pure, sometimes rapidly accumulate in lakes, bays, seas, or other bodies of water, into which they have been washed from land surfaces by rains subsequent to the settling of the ash from the air. The eruption of Santa Maria volcano in Central America blanketed the surrounding country with ash like a heavy fall of snow, yet six months later nearly all of it had been washed away.

A single ash-fall may cover a large extent of country and, if deposited on flat lands or in a large body of water where it is preserved until later covered by other materials, may make one of the most definite of geologic horizons, and one which we may be fairly certain was deposited at the same time everywhere it is found. For this reason, volcanic ash deposits are often of great value in correlating geologic strata, either on the surface or in underground borings.

Volcanic ash or pumicite has a number of uses. A large amount is mixed with small amounts of soap powder, soda ash (carbonate of soda) or other ingredients to make cleansing compounds. It is also used in abrasive hand soaps, mechanics' paste soaps, silver and other metal polishes; in dustless sweeping compounds (which consist primarily of sawdust soaked in paraffin oil, to which salt has been added to render them hygroscopic); as a filler for paint, as an abrasive in rubber erasers; for both hot and cold insulation; in tooth pastes and powders; and for polishing, cleaning or scouring many different substances. Other uses are as an insecticide, in linoleum manufacture, for filtering, as dental material, and in asphalt. Some volcanic ash has been used in California, and perhaps elsewhere, as "fuller's earth" in the refining of petroleum. Perhaps the ash so used is partially altered to bentonite or some other absorbent material. For many purposes a fairly uniform size of grain is essential.

One of the historic uses of volcanic ash is its conversion into the famous Roman hydraulic cement called Pozzuolana. This cement is made by mixing slaked lime with volcanic ash or blast-furnace slag. The mixture is finely ground but is not burned after mixing. When mixed with water, it will set like natural or Portland cement and is better adapted for use under water than in air. It weighs less than Portland cement. Pozzuolana was the material used in the Roman walls, aqueducts, and historic buildings. The Pantheon, erected of it 1800 years ago, stands intact today. Considerable volcanic ash is used as an admixture in concrete, and pumice is used in acoustic plasters.

Volcanic ash of suitable composition can now be used in large amounts in the ceramic industries. An analysis of an ash in California used for a new and desirable type of chinaware is as follows:

	Per cent
Silica (SiO_2)	78.55
Alumina (Al_2O_3)	12.73
Ferric oxide (Fe_2O_3)	0.17
Titanium oxide (TiO_2)	0.10
Lime (CaO)	0.30
Magnesia (MgO)	0.20
Potash (K_2O)	5.27
Soda (Na_2O)	0.32
Loss on ignition (water)	2.10

Volcanic ash for this purpose should be as low as possible in iron oxide, lime, and magnesia. It is the content of potash and soda in the above analysis which makes it possible to replace the usual feldspar entirely and which is the significant part of the material in connection with the high silica content. Workable deposits near Millican, Brazos County, and Carmona, Polk County, Texas, meet the requirements for chinaware, a binder for abrasive wheels, and mineral wool.

About 55,000 tons a year of volcanic ash, valued at $2 to $3 per ton, are produced in the United States. The United States in 1929 produced 60,873 short tons of pumice and pumicite, valued at $318,579. It is found in every state west of Mississippi River, but the main production is in Kansas, Nebraska, and California, some being produced in Oklahoma, South Dakota, and Arizona.

Volcanic ash is widely distributed in Texas. Great quantities are found in all the mountain counties which lie south of the line of the Texas and Pacific Railway in Trans-Pecos Texas. Deposits are known in the Panhandle High Plains and the Staked Plains and in the counties to the east (Kent, Wilbarger, Dickens, and Baylor counties). Ash is found in many of the counties of the Gulf Coastal Plain. Many of the Coastal Plain ash deposits are in part or wholly altered to bentonite.

The unaltered volcanic ash of Texas is of Tertiary and Quaternary age. The formations of the Gulf Coastal Plain which contain it in most abundance and in the thickest beds are the Fayette and Jackson of Eocene age and the Catahoula (or Gueydan or Corrigan) of Oligocene or Miocene age. There were originally volcanic ash deposits in the Cisco formation of Pennsylvanian age and in the Permian as well as in the Upper Cretaceous formations, but all of these now known have been altered to bentonite.

Pure volcanic ash of Pleistocene age in a bed 7 feet in thickness is found on the north side of Tule Canyon at the Swisher-Briscoe county line. A bed reported to be some 10 feet in thickness and extending over many acres is found along Duck Creek southeast of Spur in Dickens County. On the same creek, in Kent County, a bed of Pleistocene age, 18 feet thick, is known. A bed of Pleistocene age is found at Red Bluff, on Red River, in Wilbarger County. A bed about 7 feet thick, of lower Pliocene age, is situated in the northeast corner of Section 59, Block A-2, in Hemphill County. It is estimated that about 46,500 cubic yards of mostly fine-grained ash is available in the last noted deposit. Volcanic ash is reported from Baylor, Taylor, Lipscomb, Deaf Smith, and Cottle counties. It occurs in Donley and Hall counties. Pure volcanic ash, varying from 7 to 10 feet in thickness, occurs on the Collins ranch, on the Romero road, 6 miles west of Channing, Hartley County.

A deposit of volcanic ash said to cover an area of 350 acres and to be from 2 to 15 feet thick, is found 1 mile from Skeen station in Lynn County. Volcanic ash, at least 4 feet in thickness, outcrops along Spring Creek, 4½ to 5 miles southwest of Spur, Dickens County.

A fine-grained volcanic ash, underlying gravels, is found within half a mile of Eldorado, Schleicher County.

Among the counties of the Gulf Coastal Plain in which beds of volcanic ash have been found are Tyler, Polk, Trinity, Brazos, Washington, Fayette, Karnes, and Starr. It is probable there are beds of ash in a number of other counties also.

In Starr County, east, north, and south of Rio Grande City, there is a belt of very soft and powdery, somewhat limy, pinkish-white volcanic dust or tuff. The belt is over 3 miles wide, but good exposures are not common. Estimates of the thickness of ash here vary from 60 to 200 feet. There is an excellent exposure of the ash in this belt on the north side of the Loma de la Cruz, 3 miles east of Rio Grande City.

A deposit a short distance north of Millican, Brazos County, is of very fine texture, suitable for metal polish. An ash bed, 15 to 20 feet thick, outcrops on Brazos River 5 miles west of Millican and 1 mile above the mouth of Boggy Creek. A bed 6 feet thick of white volcanic ash is found at Sulphur Springs, 5 miles north of Chester in Tyler County. At Chalk Bluff, northeastern Polk County, there is a bed of medium-grained ash, 8 feet thick. Around Potomac, in Polk County, are deposits 5 feet and more in thickness. There are a number of exposures in the vicinity of Corrigan, Polk County.

There are also deposits in the neighborhood of Piedmont Springs and 2 miles east of that place in Grimes County. These deposits are 4 to 5 feet in thickness. There is a bed 2 feet thick on Chalk Branch 1 mile west of Kellum Springs, Grimes County. The ash is also found at other places between Piedmont and Kellum Springs. Five miles northeast of Kellum Springs, near Union Hill church, there is a deposit over 20 feet thick covering nearly 10 acres. There are also a number of exposures in the vicinity of Singleton, Grimes County.

There are a number of exposures in southern Trinity County among which is a bed 8 feet thick just north of milepost 16 on the International and Great Northern Railroad and exposures on White Rock Creek east of the town of Trinity. There are also deposits in northern Walker County. In the general area between Trinity and Neches rivers there appear to be two horizons of volcanic ash in the Jackson formation and a large quantity of it in the Corrigan or Catahoula formation.

Volcanic ash is generally worked in open cuts, from which overburden or other unsaleable material must sometimes be removed. Much of the pumice, the main source of the best grade of which is the Island of Lipari in the Mediterranean Sea, is mined in underground workings.

Volcanic ash must be of uniform texture and unmixed with other material for a number of uses. The cost of transportation, milling, and purifying—if the two latter processes are necessary—must be kept low. Although the deposits are known to be large, no volcanic ash is now being produced in Texas.

CLAYS AND CLAY PRODUCTS

Texas possesses workable supplies of all kinds of clay except ball clay. It is possible that some of the various bleaching clays, described in this work under the heading of fuller's earth and bentonite, may prove to be a satisfactory substitute for ball clay. The clay resources of Texas are abundant as well as extremely diversified and will probably be utilized to a greater extent in future years. An additional advantage is that the state has the largest known supply of natural gas, which is the fuel most suitable for the manufacture of clay products. It would be rare indeed to find a building in which there was not something made of clay and utilized either in the construction itself or as a utensil.

Clay is a fine-textured earthy substance derived primarily from the chemical decomposition and leaching of the original or igneous rocks of the earth. Secondarily, a deposit may be several generations removed from its parent igneous rock, having been derived subsequently from a metamorphic or sedimentary rock. In the case of a residual deposit remaining in place just above the parent rock body, leaching of the more soluble constituents by water solutions or gases has concentrated or purified the clay. Where the clay is transported some distance from its source rock, a gravitative sorting according to weight and texture has made possible a deposit of clay sometimes of a purity sufficient to be utilizable. Almost any substance may be present in clay as an impurity, the most common impurities being sand, gravel, iron oxides, and peaty and bituminous substances. All these are undesirable for the higher grade of clay products as are also lime, magnesia, and titanium oxide. The best clay is pure white or nearly so and composed only of silica (SiO_2), alumina (Al_2O_3), and combined water.

This best grade of clay is called kaolin, china clay, or paper clay. It is an almost pure hydrous silicate of aluminum; although where residual from binary granite or pegmatite it may contain some feldspar and quartz without their presence being deleterious to quality. Some kaolins or china clays and flint clays differ from the other and more ordinary clays in having little or no plasticity, although the china clay now known in Texas can be made plastic by being ground wet for a sufficient length of time.

Geologists of the United States Geological Survey[15] have classified clays as follows:

High-grade clays
- Whiteware clays (non-plastic and plastic)
  - Kaolin, porcelain, or china clay
  - Ball clay
  - Paper clay

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[15]Schrader, F. C., Stone, R. W., and Sanford, Samuel, Useful minerals of the United States: U. S. Geol. Surv., Bull. 624, p. 363, 1916.

- Refractory or fire clays
  - Glass-pot clay (for vessels in which materials for making glass are fused)
  - Flint clay
  - Plastic fire clay and shales
  - Graphitic fire clay
- Pottery or stoneware clays
- Medicinal clay, bentonite, Denver mud (having various uses other than medicinal, for which see the section on bentonite and fuller's earth)

Low-grade clays

- Vitrifying clays and shales
  - Terra-cotta clays and shales
  - Sewer-pipe clay and shale
  - Roofing-tile clay and shale
- Brick clays and shales
  - Loess clay (largely transported and deposited by wind)
  - Glacial clay
  - Pressed-brick clay and shale
  - Paving-brick clay and shale
  - Adobe clay (used for sun-dried bricks, plaster, and stucco)
- Gumbo
- Slip clays
- Fuller's earth

HIGH-GRADE CLAYS

WHITEWARE CLAYS

Kaolin or china clay (non-plastic).—Kaolins are residual white-burning clays, consisting chiefly of the hydrous aluminum silicates and generally possessing little or no plasticity. Whiteware clays are used for porcelain, china, whiteware, pottery, high-grade tile, and paper manufacture.

Kaolin or china clay (plastic).—A sedimentary, generally white clay containing a high percentage of kaolinite and little or no iron oxide. Its principal uses are in the manufacture of paper, sanitary ware, and tile. The plastic kaolins are sometimes referred to as china and ball clays and contain more fluxing impurities than the non-plastic kaolins. They are also often called paper clays.

Ball clays.—White-burning plastic clays of high tensile strength and bonding power and little or no iron oxide. They are extensively used as an ingredient of high-grade tile and whiteware mixtures to give the body sufficient plasticity and bonding power.

Paper clay.—A highly plastic white clay, free from sand.

REFRACTORY CLAYS

Fire clays.—Refractory or fire clays are clays which endure high temperature without change other than dehydration, but the term is frequently misapplied. Many of the best fire clays are non-plastic, this property being supplied by the addition of a small quantity of less refractory but plastic material. Comparative freedom from fluxes, such as iron, alkaline earths, alkalies, and excessive silica, is essential. The composition, both chemical and mineralogic, is similar to that of ball clay. The principal uses of refractory clays are for materials required in the industries (especially in iron and steel manufacture and in coke making) where high temperatures must be withstood.

Glass-pot clay.—A variety of refractory clay which, besides possessing refractory qualities, burns dense at a low temperature without warping and has good bonding power.

Flint clay.—A non-plastic, hard, dense refractory clay, having an appearance much like flint, a shell-like fracture, and a composition like plastic fire clay.

Plastic fire clays and shales.—Refractory clays and shales which are plastic when wet.

Graphitic fire clay.—A black clay resembling soft coal. It contains about 60 per cent silica and 30 per cent iron and alumina, and burns buff or white. It is used for the manufacture of pressed brick and converter lining and binding. It seems to be a product of the disintegration of graphitic schist or slate.

POTTERY CLAYS

The general term pottery clays includes some refractory and vitrifying clays. These clays are, as a rule, semi-refractory and burn to a dense mass. High plasticity, tensile strength, and complete retention of form while burning are essential properties. A buff color may be produced, owing to the content of iron or manganese. In ordinary practice a mixture of clays is used. Some of the products are earthen and common stoneware (both plain and decorated), crockery, and glazed ware.

MEDICINAL CLAY

Bentonite, Denver mud.—A bedded or sedimentary plastic clay which swells immensely on wetting. Mixed with glycerine it forms a proprietary medicament known as antiphlogistine. It is used in medicine and as packing for horses' hoofs; also for paper filling and sizing.

LOW-GRADE CLAYS

VITRIFYING CLAYS

Vitrifying clays are similar to pottery clays but are composed of lower grade material. They may be semi-refractory, should burn dense, and should contain considerable iron, both for color and flux. Fair tensile strength is desirable, as are also low fire shrinkage and low vitrification temperature, with a good range in temperature between incipient and complete fusion.

Terra-cotta clays and shales. — For terra-cotta ware a semi-refractory clay of good grade is preferred. When burnt, low shrinkage and freedom from soluble salts and warping are essential.

Pipe clays. — Almost any fine-grained clay that has a well-developed plasticity and a high percentage of iron, which apparently favors the formation of the necessary glaze, is suitable for pipe clay.

Roofing tile and fireproofing.—Roofing tile and fireproofing require semi-refractory clay or shale, with fair plasticity and tensile strength, which burns hard at a low temperature. Other uses are for enameled brick, hollow tile, and conduits.

Paving brick.—Material for paving brick includes many impure shales as well as semi-refractory clays. It should possess fair plasticity and good tensile strength.

BRICK CLAYS

Almost any kind of clay which possesses plasticity can be used for common brick. Red-burning clays are preferable, as they harden at a low temperature. Loess, glacial, and marine clays are also used for this purpose. Brick and drain tile are the principal products.

Loess (clays).—The term loess is applied to extensive, uniformly fine-grained deposits which are high in silica, low in alumina, and high in alkalies. Their use is confined to common brick and other cheap products. They are of Pleistocene age and are commonly thought to consist of wind-deposited dust. In the Mississippi Valley they are commonly known as bluff deposit.

Glacial clays.—Glacial clays are local deposits of generally tough, dense, gritty clays formed directly by the continental glacier or waters issuing from it into flood plains and lakes in the glaciated area of the northern United States. Those formed directly by the ice, as a rule, contain many stones. Some of the glacial clays, as in the state of Michigan, are used extensively in the manufacture of cement and pottery, as well as brick.

Pressed brick.—A fairly good quality of clay or shale is required for pressed brick. The shrinkage in air and fire must be low and the temperature of vitrification moderately low. For light-colored brick a semi-refractory clay is used.

Adobe clays.—Adobe clays are surface clays which are high in lime and hence can be used for but few products, the chief of which is adobe or sun-dried brick.

GUMBO CLAYS

The term gumbo clays is applied to fine-grained, plastic, tenacious surface clays of recent formations. Their occurrence along stream channels in the western central states suggests a relation to loess. The burned product is used largely for railroad ballast but in some places also for brick.

SLIP CLAYS

Slip clays are used for glazing. They possess the properties of fineness of grain, high percentage of fluxing impurities and low shrinkage in air, low temperature of fusion, and early maturity in burning. Their use on different clays calls for a wide range in physical properties. Color is of secondary importance, as it is more or less under control.

The ceramic uses of clays are as follows:

Refractory clay products
- Fire brick, with refractory block or tile, boiler and locomotive tile, tank blocks, and similar products
- Stove lining
- Zinc retorts
- Glass melting pots and other glass-house refractories
- Gas retorts
- Charcoal furnaces
- Muffles, scorifiers, assay supplies, and crucibles
- Saggers

- Chemical porcelain and chemical stoneware
- Mantle, rings, and special ware for gas lighting and heating including magnesia ware and refractory porcelain for electric ranges and heaters
- Potters' supplies (spins, tilts, and spurs)

Non-refractory clay products

- Common brick
- Vitrified brick or block
- Face brick
- Fancy or ornamental brick
- Enameled brick
- Drain tile
- Sewer pipe
- Architectural terra cotta
- Fireproofing and hollow building tile or block
- Conduits
- Roofing tile
- Floor tile
- Ceramic mosaic tile
- Faïence tile
- Wall tile
- Zinc condensers
- Chemical or acidproof brick, block, and tile, cylinders, rings, and other forms of tower packing used in manufacture of acids at nitrate plants, and in petroleum refineries
- Red earthenware
- Red and brown white-lined cooking ware
- Stoneware and yellow and Rockingham ware
- Whiteware, including C. C. ware, white granite, semi-porcelain ware and semi-vitreous porcelain ware
- China, bone china, delft and belleek ware
- Sanitary ware
- Porcelain electrical supplies
- Turpentine cups
- Art pottery
- Tobacco pipes
- Hardware supplies and trimmings and door knobs
- Toy marbles
- Cooking ware, including porcelain cooking utensils
- Miscellaneous (mostly non-refractory), including adobes, aquarium ornaments, arch brick for foundations, bituminized brick, burnt clay ballast, chemical brick, pipes, rings, and tiling for acid towers, chimney pots, pipes, crocks, tops, and thimbles, chuck (broken ware), clay pigeons, crushed tile for roofing, doll heads, drop bowls, porcelain filter tubes, water filters and filter stones, flue lining, garden pottery, gas logs, grave and lot markers, Indian pottery, interlocking sewer blocks, jardinieres, Holland splits, lead corroding pots, lidded pipe, light weight aggregate for concrete ships, patent rail brick to connect street railway tracks with

street paving, porcelain interiors for refrigerators, porcelain shuttle eyes and thread guides, radial chimney brick and block, radial sewer brick, ruffled brick, rustic stumps, segment brick, sewer brick, block souvenirs, stock feeders, stone sewer-trap covers, sundials, tunnel brick, umbrella stands, wall and chimney coping, and water tables.

The value of clay products manufactures in the United States has been as follows:

Year	Amount
1916	$200,890,830
1920	373,670,102
1929	373,409,391
1930	275,134,322
1931	177,562,025

Clay products imported into the United States vary generally between $5,000,000 and $11,000,000 in value annually.

The following are among the non-ceramic uses of clays:

Fillers for:
- Paper
- All grades of rubber goods from automobile tires to pressed and molded goods and hard-rubber goods
- Cotton cloth and other textile fabrics
- Linoleum and oilcloth
- Phonograph records, white celluloid goods, papier-mâché, prepared modelling compounds, soap, asbestos products, packing materials, and wall plasters

Coatings for:
- Paper
- Linoleum and oilcloth

In paint, as an inert extender; in whitewash and calcimine; in distemper paints

As a mild abrasive in polishes, tooth powders, cleaning soaps, and soap compounds

As an adulterant in candy, food products, medicinal powders, whiting, various lead and zinc pigments, plaster-of-Paris, and other products

In the manufacture of colored "chalk" and crayons

In the manufacture of ultramarine

As a source of alumina for making aluminum sulphate and the alums

As a possible source for commercial extraction of metallic aluminum

As modelling clay, for cosmetics, insulation, peanut coating, rotary-drilling mud, taxidermy, water softener, polish, and in insecticides

"The clays and the ceramic industries of Texas" by A. D. Potter and David McKnight, University of Texas Bulletin 3120, 1931, contains most of the data now available on Texas clays and discusses adequately the origin, occurrence, and properties, and the technologic methods of the clay-working industries. There has been very little investigation of Texas clays except those of the east and southeast parts of the state. In a practical modern investigation of a clay resource other than that contemplated for use as a common brick, geology, engineering, and clay technology must all be utilized. There must be available a market for the product with all costs, including that of transportation, kept as near as possible to an irreducible minimum. Neglect of these precautions has led to many failures.

In Texas, as well as elsewhere in the United States, most of the higher grade clays have been formed by processes taking place during the Cenozoic era. The bulk of these are found in the Gulf and Atlantic coastal plains of the southeastern United States. Those of Texas are in the western part of the area, but unfortunately there is little market in the states to the west and northwest. However, to the immediate north and in Texas itself there is a relatively large market which can be reached more cheaply from Texas points than from clay products plants farther east. This is the natural market for Texas clay industries.

The two main areas of chinaware and high-grade pottery production center around East Liverpool, Ohio, and Trenton, New Jersey, lesser centers being Syracuse, New York, and Los Angeles, California. The last two have natural gas. The development along Ohio River from Evansville through Cincinnati and East Liverpool to above Pittsburgh was based on formerly cheap and abundant natural gas, now no longer available. Many of the plants now produce from coal their own gas fuel. Missouri clay is used extensively for the manufacture of chinaware, pottery, wall tile, electrical porcelain, and sanitary ware. Terra-cotta, glazed tile, fire brick, and other products are at present shipped to Texas largely from Missouri. Dinnerware and sanitary ware come to Texas largely from the Ohio district. Georgia and New Jersey also ship clay products to Texas. Texas at present produces only brick, hollow tile, sewer pipe, and pottery (stoneware).

The famous foreign sources of kaolins or china clay are the Cornwall district of England, the Limoges and Sevres districts of France, Saxony, Bavaria, and the Thuringian Forest in Germany, and also districts in Bohemia and Denmark. From these European centers come most of the high-grade chinaware, porcelain, and pottery imported into the United States. Japan has recently been producing much cheap chinaware. The most celebrated of all kaolins is that of the Yangtse Valley in China, from whence comes the name of both kaolin and chinaware. The Ming porcelain, produced from the fourteenth to the seventeenth centuries A. D., has never been equalled elsewhere. The art of making the highest grade Chinese porcelain is a trade secret, jealously guarded and handed down from father to son.

Previous to 1914 most of the kaolin or china clay used in the United States was imported from Cornwall. War time necessity forced American producers to prepare their clays correctly so that now American clay equals in quality the foreign and has been substituted satisfactorily in virtually all industries. The bulk of the kaolin now imported is used along the northern Atlantic seaboard, where it has the benefit of low ocean freight rates. Practically all kaolin or china clay is purified either by washing and by settling out of suspension in water or by the use of air currents. Various successful methods for the removal of iron oxide by magnetic methods, after fine grinding and perhaps heating, are in use. Most of the American kaolins or china clays are produced in Georgia and the Carolinas, the finest grade coming from North Carolina. Pennsylvania, Maryland, Missouri, Indiana, and California have produced lesser quantities.

Ball clay is produced in south Devonshire, England. In the United States the leading producing states are Tennessee and Kentucky, smaller amounts being supplied by New Jersey, Illinois, Missouri, California, and Florida.

Stoneware clay is produced mainly in Ohio, Illinois, and Minnesota. Fire clay, the most important of all in amount and value, is produced mainly in Ohio, Pennsylvania, and Missouri, with important production from California, Kentucky, New Jersey, Indiana, Illinois, Alabama, and Colorado.

The above data show that the high-grade clays of Texas have no competitors in the territory between Mississippi River and the Rio Grande and to the southwest of Missouri.

Two occurrences of high-grade china clay are known in Texas. One is on the Oscar Medley ranch, Jeff Davis County, 1 mile north of the Fort Davis-Valentine road at a distance of 16 miles from Fort Davis. The other is in Real County, 5 miles northwest of the town of Leakey. These two clays are much alike but are not kaolinite and apparently have not been formed in the same way as it is supposed that kaolins are derived more commonly.

The Jeff Davis County locality is 12 miles by road northeast of Ryan siding on the Southern Pacific Railroad. It is in the contact zone on the western side of a granitic intrusion which measures 6 by 4 miles in dimension on the outcrop. This igneous mass was intruded through the Davis Mountains volcanics of tuffs and rhyolitic lavas and has uplifted and tilted the volcanic country rock away from the intrusive contact. A number of shallow pits have been sunk at various places in the china clay, and some of it has been shipped to the hollow tile and brick plant of D'Hanis, Medina County, and to the micolithic plant in Houston. The amount of prospecting done is inadequate for the purpose of determining the amount of china clay available. The clay has been analysed and tested by some of the country's leading ceramics experts and pronounced of very superior quality. Some of the material stained pinkish by iron oxide might be purified, but without purification it has proved to be a highly refractory fire clay.

The analysis by the Federal Bureau of Standards gives the following composition:

	Per cent
Silica (SiO_2)	51.60
Alumina (Al_2O_3)	36.75
Ferric oxide (Fe_2O_3)	0.75
Water (H_2O)	10.90

This same Bureau states that the clay is fine grained, homogeneous, and slightly plastic. The water of plasticity is 21.2 per cent based on net weight. Linear drying shrinkage is 5 per cent of the plastic length. The softening point is Orton pyrometric cone No. 34, approximately 1760° Centigrade. The clay burns to clear white color at cones number 12, 14, and 19, showing a burning shrinkage of respectively 10.1, 12.8, and 16.2 per cent.

This china clay is associated with highly silicified lavas and volcanic ash beds of many different colors, either mottled or banded.

Some of the ash has been replaced by fine-grained white silica, outcropping in bands from the china clay locality southwards to the old Barrel Springs stage station. It is suggested that the china clay has originated through the alteration and leaching of original volcanic ash, hot waters and vapors given off from the granitic intrusion having leached out the alkalies, alkaline earths, and part at least of the iron oxides, and perhaps have added some additional silica or alumina or both. In other words, the changes have been made by an action similar to that of hot springs, fumaroles, or solfataras associated with igneous activity.

The Real County china clay[16] has considerable similarity to that of Jeff Davis County. This clay also has very small quantities of alkalies and alkaline earths, analyzing mainly silica, alumina, and combined water. The deposits tested occur in two adjacent filled-in cavities, which resemble sink holes from which the adjacent limestone forming the walls and floors has been dissolved. The longer dimension of the deposits is north-south, the length averaging from two and one-third to more than three times the width. There is thus the possibility that there formerly existed a broad open fissure in the limestone, somewhat similar to those containing the quicksilver in the older workings on California Hill and Sierra del Cal in the Terlingua district of Brewster County, where there were also pipe-like or well-like sink holes and caverns containing quicksilver ores, the country rock being limestone.

The north cave contains most of the pure china clay which lies beneath sand and sandy fire clay. The south cave contains more sand and sandy fire clay and relatively little china clay. Dr. Schoch estimates 140,000 tons of china clay in the north cave and several hundred thousand tons of sandy fire clay in the two caves.

The origin of this clay deposit is not known. Dr. J. A. Udden thought that hot springs or hot vapors had deposited the material in caverns in the limestone. Neither clay nor sand can be a residual concentration from solution of the limestone. It is possible that the clay and sand have been washed into sink holes or former underground caverns from clay and marl beds occurring in the Cretaceous rocks of the general area. Such occur in the Glen Rose, lower

[16]A report by E. P. Schoch on the Real County clay is given in The clays and the ceramic industries of Texas, Univ. Texas Bull. 3120, pp. 140–160, 1931.

Fredericksburg, and Del Rio strata, and it is possible that Eagle Ford clay of the Upper Cretaceous was once present in the area. Another possibility is that volcanic ash of Upper Cretaceous age, or, perhaps more likely, of Cenozoic age, once occurred in the area and was washed into the depressions and was altered to clay either before being washed in or subsequently. Another possibility is that the clay was derived by alteration and leaching of intrusive igneous rocks. Such have not been found yet in Real County but are known in the next counties to the east, Kerr and Bandera, in the next county to the south, Uvalde, in the next county to the west, Edwards, and in Kinney County to the southwest. There is a possibility that a dike or sill of igneous rock may be found ultimately, extending either beneath or under the sides of the deposit.

Deposits of strictly residual kaolins, derived from weathering and leaching of feldspathic igneous and metamorphic rocks, such as occur in considerable abundance in the southern Appalachian and Piedmont areas of the southeastern United States, have not been found yet in Texas. Such may, however, occur in the area of pre-Cambrian rocks in central Texas and in the areas of igneous and metamorphic rocks in Trans-Pecos Texas.

Low-grade clays, suitable for refractories, sewer pipe, bricks, tile, terra cotta, stoneware, and pottery are widely distributed in Texas in sedimentary deposits of Paleozoic, Mesozoic, and Cenozoic ages. Most of these are sedimentary beds of transported clays, but probably most of the fuller's earth and bentonitic clays are residual from weathering, leaching, and alteration of beds of volcanic ash.

There is a deposit 6 feet or more thick of altered volcanic ash in the Catahoula formation of southern Brazos County which has a variety of possible uses, such as for self-fluxing china clay, mineral or rock wool, bond for abrasive wheels, or as a slip clay, metal polish, or cleanser. Some has been shipped from the McGregor farm on Peach Creek, 2 miles north of Millican, 80 miles by railroad from Houston harbor. This easily fusible clay has the following composition:

	Per cent
Silica (SiO_2)	68.56
Alumina (Al_2O_3)	18.53
Ferric oxide (Fe_2O_3)	0.72
Lime (CaO)	0.60
Magnesia (MgO)	0.12
Soda (Na_2O)	2.72
Potash (K_2O)	2.27
Titanic acid (TiO_2)	0.43
Water (H_2O)	7.00
Total fluxes	6.43

In perhaps the same horizon in the Catahoula formation is a clay 6 feet or more thick, 2 miles southeast of Carmona, Polk County, the analysis of which is as follows:

	Per cent
Silica (SiO_2)	68.34
Alumina (Al_2O_3)	15.28
Ferric oxide (Fe_2O_3)	3.44
Lime (CaO)	1.20
Magnesia (MgO)	0.88
Soda (Na_2O)	3.55
Potash (K_2O)	2.47
Titanic acid (TiO_2)	0.52
Water (H_2O)	4.70
Total fluxes	11.54

The belt of Jackson and Catahoula formations in the Gulf Coastal Plain is apt to yield more clays of the same nature when painstaking search has been made. Some of the volcanic ash beds in Trans-Pecos Texas may prove to possess similar properties.

The Wilcox Eocene formation of the Gulf Coastal Plain probably contains more valuable clays than any other formation in Texas, and, moreover, the outcrop of the Wilcox is well situated with respect to the more populous area. Wilcox clays are utilized for the manufacture of brick of different grades, hollow tile, sewer pipe, and pottery (including earthenware and stoneware). The formation contains also many deposits of fire clay. The main centers of clay-working industries utilizing Wilcox clays are the Saspamco-Elmendorf district of Wilson and Bexar counties and the D'Hanis area of Medina County, all near San Antonio; the Elgin district of Bastrop County near Austin; Athens in Henderson County; and the Texarkana district.

The Wilcox clays are non-marine and appear to have been deposited in deltas on a low and flat coastal plain. Streams depositing these clays transported them from maturely weathered, thoroughly decomposed, and leached residual soils situated to the north and northwest. These soils were derived largely from weathering of the Taylor marl, Austin chalk, and Eagle Ford, Washita, and Navarro formations of the Cretaceous, the marls and clays of which, although originally calcareous, were thoroughly leached of their lime content, as is true of the present-day residual soils of these formations. The Wilcox formation contains extensive deposits of lignite, and its clays belong to a class most often associated with carbonaceous, lignite, and coal deposits.

The association of coal and carbonaceous deposits with clays of this class is also characteristic of the Pennsylvanian formations of north-central Texas. Here the chief centers of production are Mineral Wells, Thurber, and Millsap in Palo Pinto, Erath, and Parker counties, though good clays are found throughout the Pennsylvanian belt from Red River to Colorado River. Thurber produces vitrified paving brick, and clays suitable for the same purpose are found in the vicinity of Graham, Young County, and elsewhere.

The clays utilized in the Wichita Falls district of Wichita County are in the Wichita formation of the Permian, there consisting of deltaic deposits transported from the Wichita Mountains of Oklahoma.

Excellent common brick, supplying the Dallas market, is produced at Ferris, in Ellis County. The formation is the Taylor marl of the Upper Cretaceous, and, accordingly, the clays carry from 17 to 20 per cent of calcium carbonate. Texas produces about $3,000,000 worth of clay products and clays annually.

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FULLER'S EARTH AND BENTONITE

Fuller's earth and bentonite are not in all instances the same. However, much of the so-called fuller's earth is bentonite. For this reason, the two products may be grouped together. Neither fuller's earth nor bentonite are distinct minerals. There is a wide range in the physical properties and chemical properties of both substances. Bentonite resembles most a clay but has the composition of neither kaolin nor kaolinite nor of the ordinary clay minerals. Fuller's earth, in its widest sense, is a term applied to a variety of clays and claylike substances effective in clarifying oils.

The chemical composition of fuller's earth or bentonite appears to have little to do with its utility, except in a few instances. The only means of determining the value of a fuller's earth or bentonite is by making a practical test and learning if the product will serve a particular purpose. Different bentonites and fuller's earths are not adaptable to the same uses. For example, a certain variety of fuller's earth may be suitable for the refining of only one kind of oil or at least will prove to be best for, say, one particular kind of crude petroleum.

Although it is not certain that any consistent and precise distinction of fuller's earth from bentonite is possible, it is convenient to discuss the two products separately.

Fuller's earth.—R. B. Ladoo[17] defines fuller's earth as follows: "Fuller's earth is a mineral substance belonging to the clay group and is characterized by its marked ability to absorb basic colors and remove them from oils of animal, vegetable, and mineral origin as well as from some other liquids, notably water. Many clays possess some bleaching power, but only those which have this property developed to a high degree are considered true fuller's earths. It varies greatly in color, the following being common: greenish-white, gray, olive, brown, buff, cream, and occasionally almost white. It varies from non-plastic to semi-plastic, usually but not always disintegrates easily in water, and has a high water content. All fuller's earths of value for bleaching purposes show an acid reaction to litmus. No acid is present, but the earth absorbs bases in the same way that it absorbs basic colors."

The original use of fuller's earth was for fulling or removing grease from woolen cloth, but this use is no longer important, having been supplanted by other methods. The principal present uses are for bleaching and clarifying mineral, vegetable, and animal oils,

[17]Ladoo, R. B., Non-Metallic Minerals, p. 231, McGraw-Hill Book Company, New York, 1925.

fats, greases, and waxes. There has been utilization of it as a filler for explosives, as a carrier of basic colors in making cheap pigments for printing wall papers, as a detector of certain coloring matters added to butter, whisky, and artificial vinegar, and as a substitute for talc in some pharmaceutical uses in which a high absorptive power is necessary. It is reported that highly pulverized fuller's earth has been used to spread or level the colors in certain dyeing processes.

Bentonite.—Bentonite may be exceedingly plastic or non-plastic. It is usually characterized by very fine grain size or texture, high water content, high absorptive powers, and high plasticity. It may be any color, but when fairly free from impurities, it is generally greenish-yellow or some shade of green, gray, buff, cream, or white. The plastic bentonite or "Denver mud" swells immensely on wetting and disintegrates rapidly into fine colloidal particles when submersed in water. This slaking property is often observed on outcrops, the surfaces of which swell, upon wetting, into a porous, spongy coating of fractured fragments which have broken loose from the adjacent drier part, forming humps and hollows resembling on a greatly magnified scale the eruptions produced by various diseases of the skin. However, not all bentonite will thus swell and slake. When it does so, in thick outcrops on fairly steep slopes, it sometimes flows down the hill or mountain side like a highly viscuous mud. The outcrops are usually bare of vegetation and the surfaces fluffy or peculiarly granular when dry.

The characteristics of surface exposures of bentonite or of clays or marls which contain a large percentage of bentonite are well described by Dr. J. A. Udden in his account of the Tornillo clays which surround the Chisos Mountains in southern Brewster County, Texas. Udden[18] says:

> The Tornillo clays weather in a most singular fashion. They are so fine in texture as to be quite impervious to water. Inversely they will not yield enough moisture to enable plants to grow, except where their surface has been mixed with or covered by some land drift. When rain falls, the surface of the bare clay swells up into an exceedingly sticky mud, which renders the land practically impassable to man and beast. Pools of water will stand on the ground after heavy showers and they will evaporate away by heat and sunshine

[18]Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Texas: Univ. Texas Bull. 93 (Sci. Ser., Bull 11), pp 57-58, 1907.

while only a small part of the moisture filters into the clay. When the ground dries, the clay shrinks and cracks extensively, but as the moisture only affects the upper one or two feet, the cracks are limited to the same depth. The clay retains the moisture with such tenacity that the outer layer of a moist lump will warp and break off while the kernel is yet somewhat plastic. As a result, the drying clay breaks up into irregular hard lumps, less than an inch in diameter. These cover the unweathered strata beneath to depths of from one to three feet on hills and slopes where the clay is bare. They are hard and tough, sometimes wholly separate from each other, and sometimes partly adhering. With every rain the process is repeated, the lumps swell up and are again dried and warped. The swelling as well as the warping produces a small creeping motion among the clay lumps, small in extent but evidently powerful. On slopes, gravity aids all movement in a downward direction and counteracts all other movements. In the long run the accumulated effect of this influence results in a motion in the direction of the slope. The whole bed of clay lumps thus creeps forward like a glacier. The movement is evidently very slow, but many of the clay hills show unmistakable indications of its reality in their rounded flowing contours.

Sometimes the slopes of moistened bentonite are so slick and slippery that they are like grease or semi-liquid soap.

Bentonite is composed essentially of hydrous aluminum silicate, usually containing from 5 to 10 per cent of alkalies or alkaline earth oxides (oxides of sodium, potassium, calcium, or magnesium). Alkali bentonites are those containing sodium and potassium oxides. Alkali earth bentonites are those containing oxides of calcium and magnesium. Several bentonite minerals, such as montmorillonite, halloysite, beidellite, and leverrierite have been described. These minerals resemble micas. There are various trade names such as otaylite, wilkinite, taylorite, and ardmorite.

The appearance of bentonite may be dull or powdery, but a freshly cut surface is usually waxy or tallow-like. The waxy varieties may be cut into very thin, translucent shavings. The fracture is roughly conchoidal ("shelly"), or may be platy or shalelike, or there may be no typical fracture. Ordinary clays may be mistaken for bentonite and bentonite for clays. Ordinarily the texture is so fine that individual grains cannot readily be distinguished under a high-power microscope. Unlike most clays, bentonite is generally easily fusible at a comparatively low heat.

Some bentonites when finely ground and thoroughly agitated will stay in suspension indefinitely, forming a translucent gelatinous mass. These, among other uses, are used for drilling mud. Other bentonites go into suspension more easily but do not stay in suspension.

Most bentonite, but possibly not all, is a decomposition or alteration product of igneous rock. Most deposits are the result of devitrification (formation of crystalline minerals) and partial decomposition of volcanic glass ("ash"). Basaltic intrusive dikes in Arkansas have altered to bentonite, and bentonite formed by the alteration of very ancient (pre-Cambrian) crystalline rocks in the Moffat tunnel in Colorado caused much expense and difficulty in construction. Sometimes volcanic lavas are changed to bentonite. In the ordinary deposit, water has partially altered the volcanic ash, added itself to the ash, and partially leached out the alkalies. Very likely part of the alteration was done by corrosive gases which accompanied the ash expelled from the volcano.

Probably much of the swelling, heaving, and caving in well drilling is caused by bentonites. This action may sometimes be prevented by using a saturated solution of common salt as a drilling fluid. Kerosene or lubricating or crude oil used as a drilling fluid will also sometimes prevent it.

Most bentonites suitable for oil refining contain easily replaceable calcium or magnesium oxides. These when treated with sulphuric acid are not capable of being made to assume the properties of an alkali (sodium or potassium oxide) bentonite. Other kinds of bentonite are only slightly altered by sulphuric acid. The refining of oil by bentonite apparently is accomplished largely by the selective absorption of coloring matter, both suspended and dissolved, from the crude oil, but chemical reaction seems to play a part. Hence, bentonites treated with sulphuric acid to remove the calcium and magnesium oxides are largely used in oil refining. Such processed bentonite is 5 to 16 times more efficient than non-bentonite fuller's earth. It can also be used more than once and in some cases is mixed directly with the oil. Some bentonite used in oil refining is not treated with acid.

Bentonite may be used to replace up to 50 per cent soap substance in soap. This is due to its high porosity, so that if a slightly alkaline water or soap is used, only one-half as much is necessary to form a lather, which is carried into the most minute crevices by the infinitesimal particles. The first use of bentonite was by the Hudsons

Bay Company for washing blankets. It was perhaps first used in California as a substitute for soap by a Los Angeles laundry.

Bentonite was first used in the United States in the manufacture of a medical dressing ("antiphlogistine") and as a packing and dressing for horses' hoofs. Other of the earlier uses are as a retarder in the manufacture of gypsum wall plaster; as a filler in the manufacture of paper; as a filler in soap; as a harmless adulterant in drugs and candies.

Bentonite containing alkali (sodium-potassium) oxides has been used as a base for salves and ointments. Most facial beauty clays consist of alkali bentonites made into a paste with glycerine. It can also be used in massage creams.

Bentonite, as a filler, binder, or plastic, is a good paper filler, because very efficient in aiding the retention of china clay; it can be used for fillers for oilcloth, curtain cloth, linoleum, rope, and possibly for rubber. A likely important future use in Texas will be its addition to kaolin (china clay) to give it the plasticity of high-grade ball clay for the manufacture of pottery. Texas has deposits of very high-grade china clay, but no good ball clay is known in the state.

The mechanical strength of Portland cement is increased and its time of setting reduced by adding up to 1 per cent of bentonite. There is a patented process which uses bentonite treated with mineral oil and mixed with concrete as a filler and water-proofing agent. A small amount added to stucco mixes might make them impervious to water; too large an amount added will cause shrinkage on drying.

Bentonite used as putty requires less linseed oil than whiting. There has been some utilization of it as a bonding agent in molding sands, especially for the high silica sands required in steel work. Its use in electrical insulation is patented. It is used by pencil manufacturers for indelible leads and crayons. It will remove oil and grease from glass and metal surfaces and can probably be used successfully in a number of kinds of cleansers.

Alkali bentonites have proved successful and economical in actual practice on an industrial scale for de-inking old newspapers, enabling them to be recovered for use as paper. A mill when operating at the rate of 40 tons per day of de-inked newspaper stock made an average yearly saving of $15 per ton over the cost of using ground wood pulp.[19] About 2500 tons per day of waste newspapers can be reclaimed by the use of bentonite. This use of bentonite, if expanded, would greatly reduce the cutting of forests for paper manufacture. It requires 100 years for the growth of the average tree used in paper pulp.

Acid treated bentonite is superior to either English or Florida fuller's earth in bleaching and clarifying crude brown packing-house lard. After becoming so filled with greasy impurities that it no longer functions as a clarifier, this product is used to make soap.

Bentonite is also an ingredient in the so-called zeolite water softeners. Other suggested uses of bentonite are in horticultural sprays, animal dips, insecticides, fungicides; in cold-water paints, calcimines, enamels, printers' ink, and oil paint; in wood dips, roofing preparations, waterproofing, dusting agents, and absorbents.

Bentonite has been found in Texas in Pennsylvanian, Permian, and all the Upper Cretaceous and Tertiary formations. The bentonite of youngest age now known in Texas is a bed fully 10 feet thick, situated on the banks of East Sandies Creek, 3 miles northwest of Rock Island, in Colorado County. This bed is in the Lissie formation.

Bentonite produced in Bexar County is in the Taylor formation of the Upper Cretaceous. The remainder of the bentonite (or "fuller's earth") now produced in Texas is in the Catahoula (Corrigan), Fayette, and Jackson formations of the Gulf Coastal Plain. Most of the Texas production has come from Walker, Grimes, Burleson, Fayette, Washington, Gonzales, Karnes, and Live Oak counties, but deposits are known in other Gulf Coastal Plain counties. Bentonite is found in Brewster County in the southern part of Green Valley and in the belt of the Tornillo clays surrounding the Chisos Mountains in the Big Bend. It will probably be found in other parts of Brewster County and at places in Presidio, Hudspeth, and Jeff Davis counties in which one would expect to find it in the Upper Cretaceous and the volcanic rocks. Thick beds capped by volcanic ash occur in Hartley County, along the Romero road 6 miles west of Channing.

Most consumers of bentonite desire a homogeneous product which is in sufficient quantity to yield for years a uniform supply. Many

[19]Davis, C. W., and Vacher, H. C., Bentonite, its properties, mining, preparation, and utilization: U. S. Bur. Mines, Technical Paper 438, p. 38, 1928.

crude bentonites contain impurities such as sand, clay, gypsum, carbonate of lime, soluble mineral substances, or carbonaceous matter. These must be removed by washing. Different layers in a single deposit may vary greatly in properties. There is so much bentonite in Texas that a prospective producer must thoroughly investigate the possibility of marketing, transportation costs, the price, the cost of working, milling, and treating, the amount available in the deposit, and its suitability for the consumer's requirements.

Commercial practices.—There are so many different processes of milling, preparing, purifying, chemically treating, and utilizing fuller's earth and bentonite that they cannot be described herein. Some of the methods, processes, and utilizations are trade secrets or patented processes. A few, however, will be mentioned.

The earth is usually dried under cover in well-ventilated bins or is mechanically turned over several times on the floor of a shed. One large petroleum refiner ships the crude earth after such preliminary drying and then, as the first step in further processing, submerses the earth in hot water. Usually the earth is crushed with rolls. It is ground to coarse grain for petroleum refining, but for edible oils the grinding is to fine grain, since the finer the grain the better the bleaching power, but extremely fine grain unduly increases oil absorption and makes filter pressing difficult. Perhaps more ordinarily, accurate grading into sizes from 15 to 60 mesh is required for petroleum refining and one size, 100 to 120 mesh, for edible oil refining. The difficulty is to find uses for the fine-grained material produced in grinding; much of this appears to be yet a waste product.

The bleaching power of some, and more especially the English, fuller's earths is reduced or destroyed by heating to a temperature which drives off the combined water. The American earths used in petroleum refining are not usually impaired by high heat.

Since crude cottonseed oil is unaffected by fuller's earth, it is necessary to treat the oil with an alkali to remove the fatty acids and convert the coloring matter into basic forms. Then usually 1½ to 6 per cent of earth is added to the oil in vats heated by steam coils. The mixture is rapidly agitated a short time by paddles and then run into a filter press. When the leaves of the press are full, as much oil as possible is blown out by steam and usually also by a jet of air. Some earths spontaneously ignite in the presence of air when they contain oil. Most fuller's earth gives edible oil an objectionable odor and taste, but the oils may be deodorized by a steam treatment. Generally the earth is used only once in edible oil refining.

A number of the large petroleum refiners have their own deposits, but some of them sell a considerable part of their product. Generally the petroleum refiners use the same earth more than once, revivifying it by heat or other treatment. Sometimes the petroleum products are mixed directly with the earth as in the cottonseed oil refining process. Other petroleum refiners put the earth crushed to a size which passes through a 15 mesh but not through a 30 mesh screen in tall cylindrical percolators and force either hot or cold oil through them under pressure. When the earth will no longer remove all the color from the oil, the percolator is blown out with air, the earth cleaned of its oil by being washed with naphtha and the naphtha blown out with steam. The earth is then removed from the percolator, burned in a rotary kiln at a heat not high enough to cause incipient fusion, then cooled, and used over again. Ordinary earths may be used ten to sixteen times in petroleum refining.

English fuller's earth is not used in the United States for petroleum refining. Some edible oil refiners still prefer the English earth, probably because it is better prepared, being more uniform, more carefully kiln-dried, and more properly ground.

The United States and England are now the leading producers of fuller's earth and bentonite. The United States uses about 90 per cent of the world's production and exports considerable product used in petroleum refining; it has now a virtual monopoly on earth used in mineral oil refining and has greatly supplanted English earth in the domestic market. It is not likely, however, that the United States can retain its virtual monopoly, for bentonite, at least, is widely distributed over the earth.

One large petroleum refiner ships the prepared earth in tank cars, saving thereby costs of filling bags, of the bags, of handling, and preventing waste through leakage of bags, and eliminating danger of the earth's getting wet. One of the large expenses or losses in the open pits is that the earth which becomes wet must be dried at an increased cost.

Production statistics.—Fuller's earth and bentonite are grouped together in the production statistics. Occurrences have been reported in Alabama, Arizona, Arkansas, California, Colorado, Georgia, Illinois, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New York, Pennsylvania, South Carolina, South Dakota, Texas, Utah, Virginia, and Washington. The production in 1930 was from Colorado, Florida, Georgia, Illinois, Massachusetts, Nevada, and Texas. The production has increased steadily since 1921, reaching a maximum in 1930. Of that consumed in the United States in 1930, 98 per cent was produced in this country.

Texas has produced, up to the end of 1932, a total of 393,542 tons of fuller's earth, of a total value of $4,045,548. Texas produced 45,503 short tons in 1930, valued at $443,477 or $9.75 a ton. Georgia, Florida, and Texas produced 82 per cent of the 1930 total. Nevada ranks next after the above states in production.

The United States production in 1930 was 335,644 short tons, valued at the mines at $4,326,705, or an average of $12.89 per ton. Imports in 1930 were only 29 per cent of those in the year 1914, the year of greatest imports. Wrought or manufactured earth made up 94 per cent of the amount imported in 1930. The 1930 imports were 7258 tons, valued at $156,520.

Seven United States operators report 1930 exports of 14,237 short tons to Argentine, Belgium, Canada, Canary Islands, Cuba, Denmark, England, Germany, Mexico, Poland, Russia, and Sweden.

Fuller's earth is now being produced in Texas by the following companies: Coen Company, Inc., Gonzales, Gonzales County; Continental Oil Company of Delaware, Riverside, Walker County; Crown Central Petroleum Corporation, Fayette County; Standard Fuller's Earth Company, Macdonna, Bexar County, and Grimes County; The Texas Company, West Point, Fayette County, and Riverside, Walker County.

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COAL AND LIGNITE

The United States Geological Survey estimated the total workable area of bituminous coal in Texas to be 8200 square miles with a possible additional area of 5300 square miles. The original supply of coal was about 8 billion tons. The total workable area of lignite in Texas was estimated at 50,000 square miles with a possible additional area of 10,000 square miles, or a total of 60,000 square miles out of a total of some 127,000 square miles for the entire United States. The original supply of lignite was estimated to be about 30 billion tons. This estimate is, however, no more than a guess, because the lignite beds are lenticular, and poor roof conditions and water will render much of the lignites unworkable. Brown coal is a better term than lignite for the Texas low-grade coaly fuel, because little of the Texas material retains a woody structure, but the usage of the word lignite has become so general that probably it can not be supplanted. Ninety-nine per cent of the original supply of Texas coal and lignite is still in the ground and assures a great reserve for the future if and when needed. A cheap fuel supply is one of the most important heritages of mankind.

Texas lignites can be most efficiently used by the establishment of large central power plants in the mining territory, saving waste and expense of handling and transporting the fuel. The lignite will be converted into gas, either in producers or in retorts, and this gas will be sold for fuel purposes direct or converted into electrical energy. A number of valuable by-products from the lignite tar and ammonia will be produced. If the lignite is distilled in retorts, until most of the volatile and combustible matter has been driven off as gas, one of the by-products is carbonized lignite, consisting mainly of fixed carbon, which by the addition of a suitable binder, such as tar, pitch, or petroleum asphaltic residuum, can be compressed into briquets and burned like anthracite for domestic heating, locomotive and other power and heating purposes. These briquets, however, will run high in ash. Raw lignite, as used, contains from less than one-fourth to more than one-third water and is higher in oxygen than other grades of coal. Part of the heat is consumed in driving off the water.

Coal and lignite are formed out of the remains of plants, a fact proved abundantly by the occurrence in them of trunks, stems, twigs, leaves, and seeds visible to the naked eye and by microscopic study where plant structures are more minute. The most difficult problem in coal formation is to account for the wide extent of a single bed, because it is a necessary condition in such beds that inorganic detrital sediment was excluded for the most part from the coal bed. Peat, the first stage in coal formation, is being deposited in many places today, but peat bogs have relatively small areas. Some coal beds (and most modern peat) were formed from vegetation which grew in the places where the coal beds accumulated; others were formed from vegetable material transported from somewhere to the place where it was deposited; and some coal beds were formed by a combination of both conditions. There are still some geologists who think that practically all important coal beds were produced during a warm, if not tropical, climate, but most of the peat now forming is found in cool, temperate, or even cold (subarctic) climates, the only tropical peat bogs of any magnitude now known being found on the island of Sumatra in the Dutch East Indies. In New Zealand, Chile, and the northwest coast of North America, peat is now forming, and luxuriant vegetation grows within a very short distance of glaciers. In cooler climates decomposition or destruction of organic matter is inhibited; therefore, other things being equal, accumulation of peat and ultimately coal is apt to be favored by a cooler climate. On an open surface all vegetable or other organic matter will completely decay, most of it changing into gases which pass into the air. Therefore, most coal, at least, must form under swampy or boggy conditions, or in shady areas where the ground surface is very moist, or else where the vegetable matter is actually immersed in water. The surroundings of such bodies of water or swamps may possibly in some cases have a dry climate. Some desert oases have very luxuriant vegetation, as, for instance, the Lake Chad district on the southern edge of the Sahara Desert and swampy areas along the river Nile, but pure coal is not apt to form in such places because the wind brings in large quantities of sand and dust.

Fossil shells are not apt to occur in coal beds. Either the stagnant waters in which coal formed contained substances unfavorable to the growth of shelled animals or else the lime carbonate of the shells was dissolved after the death of the animals. Rocks immediately above or below coal beds may contain abundant fossil shells.

The conditions under which lignite was formed during Eocene time in the Gulf Coastal Plain of Texas were probably mainly the same as during the Cretaceous and Pennsylvanian coal epochs in Texas; hence only the Eocene history will be discussed. The necessary conditions, other than those already considered, are a low flattish marginal area of the Gulf of Mexico with a number of fairly extensive shallow marshes, lagoons, or lakes into which the drainage carried very little clay or sand. The rainfall was sufficiently great to foster a luxuriant vegetation in the vicinity of the areas where coal was forming.

It is difficult for the present-day inhabitant of the Atlantic and Gulf Coastal Plains of the United States to realize what the actual conditions were before settlement of the country took place. Even the Indians had disturbed natural conditions to some extent by their practices of agriculture and of burning the forests and grasslands in pursuit of game. The nearest approach to really natural conditions to be found anywhere today is in those parts of the Amazon, Orinoco, and Paraguay basins of South America and of the Congo basin of Africa still inhabited only by aborigines. The writer has seen parts of the Paraná basin of Brazil in which, although the country is very hilly, streams will run water nearly as free from sediment at the end as at the beginning of six months of the rainy season. The main northern tributary of the Amazon, the Rio Negro, derives its name from the fact that its water is dark brown from the very finely comminuted vegetable matter which it carries in suspension. The Rio Negro derives very little of its water from highland areas and consequently carries very little inorganic sediments. It therefore differs from most of the larger streams in the various basins already mentioned, these in general having their headwaters in highland areas where considerable erosion is taking place. However, much of the region of the Paraguay flood-plain, of the Llanos of the Orinoco, and of parts of the Amazon basin is flat and low-lying, a labyrinth of lakes, ponds, swamps, channels, and islands in a grassy plain, the only forest being near the river. When the rivers are at their highest, the whole plain is a vast lake covered with floating grass and weeds.

The Gulf Coastal Plain of Texas, in a belt about 50 miles wide bordering the Gulf of Mexico, has like characteristics, and many of the shorter rivers, bayous, and other drainage courses are entirely within this flattish country. During primeval times, before the region was grazed, farmed, or the timber cut, these sluggish streams carried very little inorganic sediment.

It was not, however, along the courses of the flowing streams that pure coal mostly accumulated but in the undrained marshes, lagoons, ponds, and lakes between the streams. The streams themselves form deltas, and their banks have higher depositional ridges or natural levees. Undrained areas are left in the depressions between the deltas and natural levees and the abandoned "ox-bow lakes," which are parts of abandoned stream courses. Since settlement of the country not only has the amount of sediment increased but also the floods have become greater, for water is no longer held back by forests and grasslands but flows off rapidly after rainfall.

However, probably the most favorable areas for coal formation are the coastal lagoons and marshes, cut off by depositional deltaic ridges from the larger stream courses and separated from the Gulf by barrier sand bars. A wide area of very shallow water existed off the shore, and the barrier bars were formed where the waves break as they approach the shore. If uplift of the coastal margin took place it might leave a number of these barrier beaches, flanked on the landward side by lagoons and marshes. In the coastal section of North Carolina and Virginia today we find a number of these uplifted beaches and bars, and behind them are extensive marshes, of which the Dismal Swamp is perhaps the most noted example.

The two greatest peat-forming marshes of North America are the Everglades of Florida, with an area of about 4000 square miles, and the great Dismal Swamp of Virginia and North Carolina, 2200 square miles in extent. The main peat formed in the Everglades is from sawgrass, whereas trees—black (tupelo) gum, white cedar and cypress—and extensive canebrakes form most of the peat of the Dismal Swamp.

The Dismal Swamp lies between Hampton Roads, the estuary of James River, on the north and Albermarle Sound, the estuary of the Roanoke and Showan rivers, on the south. It occupies the area of the Dismal Swamp marine terrace which here has an altitude of from 12 to 25 feet above sea level and is bounded both east and west by former shore lines of the Atlantic. It is part of an area recently added to the land. Not so long ago it was covered by the ocean, then an uplift took place which raised it to above its present level and enabled James and Roanoke rivers to cut deep channels, then a sinking took place "drowning" the lower courses of the rivers and forming the present estuaries. The rainfall over the Dismal Swamp is about 52 inches per year, and the average humidity of the air is 73 per cent. The peat deposits range from 1 foot to 20 feet in thickness and total about 672,000,000 tons. The water, except in Lake Drummond, is rarely more than 1½ feet deep and averages from 1 to 3 inches, although in many places the average depth is from 6 to 8 inches. The floor of Lake Drummond is covered largely with white sand, and its water is light brown in color, due to a considerable amount of finely divided vegetal matter in suspension. This water is famous for its keeping properties and has been used extensively for supplying ships for long voyages.

Dr. N. H. Darton[1] accounts for the formation of Dismal Swamp as follows:

The basin of the Dismal Swamp owes its origin to an extensive depression in the surface of the Columbia (Dismal Swamp terrace) formation. At first this hollow was probably a slough in the terrace surface. When the Columbia formation was deposited, James River had essentially its present course but opened into open water some distance northwest of the Swamp. Its main current appears to have built a bar or broad delta which extended eastward and thus built up the terrace plain that lies east and southeast of Norfolk. Between this delta and the steep slope at the edge of the highlands which lie a short distance west of the Norfolk quadrangle there remained an area of lowland, a slough which was not built up appreciably by the Columbia deposits. When the delta was uplifted it became a high terrace with good drainage conditions, while the slough became a swamp filled with luxuriant vegetation, and it has so continued ever since. At first, when the vegetation was young, relatively fine-grained peat accumulated, but as the forest grew older, roots and trunks were intermixed with the finer materials, and finally the depression was filled up to the general level of the country by these accumulations. It is now so remote from the larger drainage ways and so choked with canebrakes that its drainage is still very imperfect, and the swamp conditions continue over nearly all the original basin area. Lake Drummond is no doubt the remaining portion of an original center pond, probably greatly encroached on by the forests and canebrakes. . . . Its bottom has been raised somewhat by vegetal accumulations, but probably its water level has just about kept pace with the general rise of the swamp surface.

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[1]Darton, N. H., Description of the Norfolk quadrangle: U. S. Geol. Surv., Geol. Atlas, Norfolk folio (No. 80), p. 1, 1902.

The Dismal Swamp has some small aquatic plants which live either submersed, floating on the surface, or rising above the surface. Among these are mosses, like Sphagnum, pondweeds, water lilies, ferns, sedges, and rushes which make most of the peat in more northe n climates. The larger vegetation includes one shrub, rattan, cane, water ash, yellow jessamine, cross vine, and among trees, gum, red maple, cypress, loblolly pine, sweet bay, and white cedar.

The highest part of Dismal Swamp is the water level of Lake Drummond, just as the highest part of the Everglades is the water level of Lake Okechobee. Both are about 22 feet above sea level. The dense mat of vegetation holds the water somewhat like a sponge, and hence the peat can form on a surface which slopes seaward from three-tenths of a foot to a foot per mile. A depression in the surface is therefore not necessary in order that peat may accumulate.

However, marshes do not start on fully drained land, and it is necessary to have some initial depression, however slight. When the sea withdrew from such areas as the Dismal Swamp or the Everglades it did not do so suddenly or at a uniform rate but during a series of stages with halts at several levels for greater or lesser time. During these halts barrier beaches or shore ridges were built up by the waves, the depressions behind and landward of which became the sites of lagoons and marshes in which peat started to accumulate. Once the marsh forms, its area expands by the dense mat of vegetation holding back the water which accumulates, and in time the peat bog may be built up above the original depression and its surface come to have a very gentle slope seaward. Cypress and tupelo gum trees grow in abundance in the shallow stagnant waters of the marsh except in Lake Drummond, which is a deeper portion in which floating vegetation sinks upon becoming waterlogged, its water being too deep to permit tree growth.

Peat, once formed, gradually changes during the course of geologic ages into lignite, brown coal, and the various varieties of bituminous coals. It is necessary for the peat to be covered by later deposits which, gradually accumulating, compact the lignite by pressure from above. In the process of gradual change, part of the volatile hydrocarbons gradually escape as gases and the percentage of "fixed carbon" increases, becoming greater in the higher grades of coal. The process of gradual evolution from peat is through the stages of lignite, sub-bituminous, bituminous, and semi-bituminous to semi-anthracite coal. It is a general rule, though not without some exceptions, that the older the deposit of coal the higher is the percentage of "fixed carbon." Semi-anthracite, anthracite, and graphite are produced by gradually increasing metamorphism in the order named. This metamorphism is brought about either by the heat and pressure produced by rock deformation or by the heat of the intrusion of igneous rocks. In areas in which the rocks lie horizontal or nearly so and in which igneous rocks do not occur, coal even as old as Devonian or Carboniferous seldom attains a rank higher than bituminous.

Graphite is pure carbon, which cannot be burned except at extremely high heat. Crystalline graphite occurs in the strongly metamorphosed, very old schistose rocks of pre-Cambrian age in Llano, Burnet, and Mason counties of central Texas. Small amounts of amorphous graphite occur in the proximity of igneous intrusions in the southern part of the Big Bend in Brewster County, where Cretaceous coal beds have been metamorphosed by the heat of the igneous rocks.

The volatile substances, calculated on the ash-, moisture- and sulphur-free basis, amount to more than half the composition of lignites, range from 46 or 47 to 25 per cent in bituminous coals, from 25 to 17 per cent in the semi-bituminous, from 17 to 7 per cent in the semi-anthracite, and from 7 per cent downward in the anthracites, which verge into the graphitic stages.

Peat has been burned for fuel in northwestern Europe since man has made use of fire. Its use in Germany was noted by Pliny. Coal was probably first utilized by the Chinese, but Aristotle, in the fourth century B. C., was the first to record its use. The real utilization of coal began only in the seventeenth century A. D. The blast furnace and coke were developed about the middle of the eighteenth century, previous to which wood charcoal had been used for the smelting of iron. The invention of the steam engine marked the next great step in the utilization of coal and was responsible for the beginning of the industrial revolution in the first half of the nineteenth century. The utilization of steam destroyed much handicraft and hand labor, ruined the guild system of production, speeded up transportation enormously, and finally so greatly supplanted hand labor and consequently permitted the concentration of capital in the hands of so few that it was certainly one of the major factors which brought on the great crisis of 1929 to 1935.

Since the invention of the blast furnace about 1750 and of the steam engine in 1769, coal and iron have dominated the world's industry and through this domination have been the controlling force in history. For nearly two centuries the nations with suitable supplies of coal and iron near each other have advanced at the expense of nations not so well favored. Great Britain, Germany and the United States mainly have been favored by Nature in this respect; Russia has abundant supplies of both coal and iron, but the two are far apart. Other metals and raw materials have been drawn towards the centers of coal and iron production. The results have not been entirely happy, because they have led to congestion of population in limited districts, unhealthful conditions of existence, and a superabundance of smoke, fumes, grime, and dust, dependence on the outside for a food supply, and dependence of the outside for manufactured goods with a financial dominance of industrial centers over the rest of the world.

The population of Great Britain remained practically the same from the middle of the seventeenth to the middle of the eighteenth century. After the discovery of the process of coking coal and of the hot-blast furnace, English population greatly increased, the nation built up a vast colonial empire, and won the lion's share of the world's commerce by the development of shipping and the conversion of raw materials into finished products. In the meanwhile, such countries as Italy, Spain, France, and Ireland diminished in relative importance. In Roman days, before the depletion of the agricultural resources and forests, Spain had a population of about fifty millions, at the time of the discovery of America between seven and eight millions, in the days of Queen Elizabeth more than twice as much as Great Britain, whereas now Spain's population is less than half that of Great Britain. In 1910 France mined 38,000,000 tons of coal while Germany mined 221,000,000 tons. Therein we find one of the reasons for the Great War. Today despite great losses in and since the war, Germany with 181,723 square miles has a population of 63,000,000, while France, with about equally good agricultural resources and 212,659 square miles, has only 41,000,000 people.

Texas has iron ores, although not greatly diversified in quality. However, the coal in this state occurs in thin beds, is high in sulphur and ash, and will not form good coke for iron making. Therefore, industrially the state has lagged behind the north and east. Those areas, rich in both coal and iron, developed industrially before Texas had a chance.

More metals and other mineral resources have been used in the last thirty years than in all previous time. Coal resources have not been greatly depleted, but high-grade iron ore, cheaply accessible, is becoming scarce. Rustproof iron and steel are being made in increasing quantities. An increasing amount of iron and steel and other metals in the form of "scrap" is being used. Alloys and other metals increasingly are being used as substitutes for iron and steel. Conservation of the world's metal supply, because of increasing demands, has become a problem of the highest import. Conservation of fuel and power resources is not so pressing. Water power is not being depleted, and peat is perhaps accumulating as fast as coal is burned. Oil and gas are being depleted more rapidly than coal, but coal can be converted into both. Other sources of power, like the utilization of the sun's energy, the interior heat of the earth, and atomic disintegration are possible, but there is no prospect of increasing the supply of metals.

Is there a substitute for coal in iron smelting? The electric furnace is being increasingly used, although costly because so far only small units are workable. Gas and oil are being used to smelt copper, zinc, lead, and silver. According to some non-ferrous metallurgists, the smelting of iron ore and the making of steel by the use of oil or gas as a fuel are within the realm of commercial possibility. Much prejudice, ignorance, and tradition must be overcome before oil or gas will be given a fair test in comparison with coke, one of the drawbacks being that the iron and steel corporations have much money invested in coal properties.

Most of the coal produced and sold in the United States is used for the following purposes: industrial fuel, power, metallurgical coke, domestic heating, electrical utilities, coal gas manufacture, smithing, railroad, steamship, and steamboat transportation.

Producer gas is coal gas diluted with air and often mixed with water gas. Water gas is largely carbon monoxide and hydrogen, made by dissociating steam into hydrogen and oxygen, permitting the oxygen to unite with carbon from anthracite, coke, or non-coking coal, and form carbon monoxide. Illuminating gas made from coal is now largely supplanted by electricity.

Powdered fuel is coal pulverized exceedingly fine and blown into the combustion chamber with plenty of air added to it. It is entirely feasible to transport such powdered coal by means of compressed air through a pipe line. The very finely powdered coal when suspended or perhaps partly dissolved in fuel oil is known as colloidal fuel. Some Texas lignites when soaked with hot fuel oil under pressure not only have an enhanced fuel value but do not slake. The finer slack and waste products of all grades of coal can be used in briquets formed under pressure with the addition of a suitable binder.

It is now known that all coal can be changed into gasoline or motor fuel by the process of hydrogenation. Paraffin and lubricating oils have been made from coal. High explosives have coal as one of their constituents. As by-products in the production of coke and gas from coal the following are important: tar, pitch, creosote, electric light carbons, printing ink, lamp black, lubricating oil, solvents, disinfectants, unguents, medicines, coal tar dyes, and anilines. From coals containing sufficient nitrogen, ammonia products valuable as fertilizers are obtainable. There seems to be a possibility that non-coking coals may be changed to coking by some preliminary treatment.

The coal industry of North America has suffered from the competition of petroleum, natural gas, and water power. As a result, coal mining is done much more by machinery than formerly and, where feasible, open-cut rather than underground mining is done. Much greater efficiency is possible by turning coal at the mines into electric current, thereby saving valuable by-products as well as waste and handling and transport charges. Great savings can be accomplished by converting the coal at the mines into oil and gas and transporting them by pipe lines.

PENNSYLVANIAN COAL

It now appears probable that coal beds in the Pennsylvanian are more numerous but far more localized than the seven beds originally listed by Cummins. He thought that all the workable coal beds of the southeast belonged to his No. 1 bed which he placed at the top of the Millsap, that Nos. 2 to 6 inclusive were from a foot to less in thickness and too poor to work except at Chaffin, and that No. 7 was the main workable bed of the Cisco, extending all the way from Bowie, Montague County, to Waldrip, McCulloch County.

Scott and Armstrong[2] state "that coal seams in the Pennsylvanian of north-central Texas become more numerous towards the northeast. In the Wise and Jack county areas coal seams (not including the bed here referred to the Thurber) have been encountered in wells in the different formations and groups of the Pennsylvanian as follows: Millsap formation, 3 beds; Mineral Wells formation, 3 beds; Canyon group, 2 beds; and Cisco group, 11 beds. Additional seams are found farther to the southwest in the Bend strata; and the Bend probably contains coal under Wise County. In all cases it is apparent that the extent of the individual coal seams parallel to the strike greatly exceeds their extent parallel to the dip."

To the above statement the writer will add that probably no individual coal seam in Texas is as extensive areally as the Pittsburgh coal, because the Pennsylvanian rocks of the United States pass southwestwards in Texas into dominantly marine sediments, and, secondly, that no one has determined the number or extent of Texas Pennsylvanian coals, because the data furnished by well logs are unreliable, and certainly black shale and carbonaceous shale often are reported erroneously as coal by the driller.

The Thurber coal is the base of the Mineral Wells formation of the Strawn group. It was mined at Thurber, Gordon, Strawn, and Rock Creek. Its thickness is 18 to 28 inches. The thickness in the mine at Rock Creek, Parker County, is 22 inches, at the Strawn mines, in southern Palo Pinto County, it is 26 inches, and in the Thurber mines, in northern Erath County, the average thickness is 28 inches. The B. T. U. value of the coal ranges from 11,800 to 13,750, the fixed carbon percentage ranging from 40.8 to 52 per cent. The coal will coke.

The coal at Bridgeport, Wise County, occurs near the top of the Palo Pinto formation of the Canyon group. It is found from Bridgeport to the outcrop southwest of Perrin but does not extend far underground down the dip. In places limestone directly overlies the coal. The Bridgeport coal is 18 to 22 inches thick, sub-bituminous

[2]Scott, Gayle, and Armstrong, J. M., The geology of Wise County, Texas: Univ. Texas Bull. 3224, pp. 17-18, 1932.

with a fixed carbon ratio of 46 to 47 per cent and a B.T.U. value of 12,000. The Bridgeport mine was the last bituminous coal mine to cease operation in the state.

The Chaffin coal is in the Thrifty formation of the Cisco group. It is known only to occur at the Chaffin mine, 2 miles east of Waldrip, northern McCulloch County, where it is 20 inches thick and overlain by limestone. The coal was considered to be higher in grade than is usually found in this region, but the thinness of the bed and its distance from a railroad have prevented its being worked successfully commercially. There appears to be no analysis available.

Coal occurs in the Harpersville formation of the Cisco group, being found about 60 to 80 feet below the Saddle Creek limestone. The coal beds are variable in thickness, not occurring at exactly the same horizon in all outcrops though confined to an interval of 80 to 100 feet. In places there are two or more coals in the same section. Workable coal, however, occurs only locally, most of the coal being shaly, thin, and of inferior quality. The coal has been worked in the vicinity of Waldrip, northern McCulloch County, and at Rockwood (Vining), southern Coleman County, but is there too thin and of too low grade to be profitable. The coal has been mined at Cisco, Eastland County, at Newcastle, Olney, and Loving, Young County, and near Bowie, Montague County. The bed varies from 12 to 42 inches thick, being about 40 inches with a 6-inch bed of shale near the middle in the Bowie mines. From Bowie to Cisco, southwestward through Jack, Young, Stephens, and northern Eastland counties, the coal varies in thickness from 12 to 42 inches and contains from one to several shale partings. In the vicinity of Cisco it is 33 inches thick but is separated by two beds of shale 4 to 20 inches thick. Between Cisco and Home Creek, near Colorado River, the coal is broken by interbedded shale. On Home Creek, Bull Creek, and at the Vining mines in southern Coleman County, it varies from 28 to 34 inches in thickness, usually containing a thin parting of shale. Around Waldrip the coal is about 2 feet thick. The fixed carbon ranges from 42 to 61 per cent and the B.T.U. value from 10,970 to 12,700.

All the Texas bituminous coal was mined by the long wall "advancing" method.

Analyses of Texas Bituminous Coals of Pennsylvanian Age, Proximate Analyses by Texas Geological Survey, 1890

						Fuel Constituents		
No. of coal bed and mine	Moisture	**Volatile** combustible **matter**	Fixed carbon	Ash	Sulphur	**Volatile** combustible **matter**	Fixed carbon	Fuel ratio
Bridgeport, Wise County	2.00	31.47	56.32	8.15	2.06	35.84	64.16	1.79
No. 1, Thurber, Erath County	.88	31.57	56.81	8.93	1.97	35.72	64.28	1.79
No. 7, Bowie, Montague County	2.30	34.48	61.28	.60	1.14	36.00	64.00	1.77
No. 7, Vining, Coleman County	4.05	40.40	46.75	8.80	2.87	46.35	53.65	1.15
No. 7, Bull Creek, Coleman County	10.40	35.94	49.46	4.19	1.53	42.08	57.92	1.37
No. 7, Rockwood, Coleman County	3.23	37.54	42.80	16.40	3.67	46.73	53.27	1.14
No. 7, Waldrip, McCulloch County	4.55	36.50	44.80	12.14	7.96	46.21	53.79	1.16
No. 7, Rockwood, Coleman County	3.07	33.05	39.10	24.78	3.10			
No. 7, Silver Moon mine, N.E. of Santa Anna, Coleman County	2.36	38.55	43.88	15.21	5.91			
No. 7, Lost Valley, Jack County	10.28	25.49	55.10	9.13				
No. 7, Bowie, Montague County	9.00	28.00	47.22	14.04	1.74			
No. 1, Strawn, Palo Pinto County	1.06	39.28	50.12	9.54	2.88			
No. 7, west of Crystal Falls, Stephens County, upper bench	6.90	38.07	37.03	18.00	6.49			
lower bench	3.15	41.95	43.60	11.30	3.75			
No. 7, Gordon mine, Young County, lower vein	9.04	48.90	30.28	11.78				
No. 7, Loving, Young County	18.00	30.91	40.18	10.91	1.11			
No. 7, Loving, Young County	18.50	31.70	37.10	12.70	1.92			

Dry Basis Analyses of Texas Bituminous Coals of Pennsylvanian Age

No. of coal bed and mine	Moisture	Volatile and combustible matter	Fixed carbon	Ash	Sulphur	B. T. U.
No. 7, Cisco, Eastland County	13.44	40.28	42.02	17.70	2.94	11101
No. 1, Thurber, Erath County	2.70	41.95	50.08	7.97	1.98	12526
No. 1, Thurber, Erath County	5.36	33.72	45.47	20.81	2.16	12099
No. 1, Thurber, Erath County	5.46	37.72	52.01	10.27	1.71	13755
No. 1, Thurber, Erath County	5.83	35.26	45.83	18.91	2.77	12157
No. 1, Thurber, Erath County	4.31	37.22	46.56	16.22	3.14	12817
No. 7, Jermyn, Jack County	10.24	38.18	39.01	22.81	1.84	10510
No. 7, Lost Valley, Jack County	10.28	28.11	60.77	11.12		
No. 1, Strawn, Palo Pinto County	1.05	39.70	50.65	9.65	2.91	13563
No. 1, Strawn, Palo Pinto County	4.00	33.11	43.80	23.09	2.49	12005
No. 1, Rock Creek, Parker County	2.90	39.60	49.56	10.84	3.17	12265
Mine No. 1	8.12	32.24	49.90	17.86	1.70	12533
Mine No. 2	5.95	35.18	47.63	17.19	2.13	12175
No. 1, Keeler, Parker County	5.31	33.00	40.86	26.14	5.03	11797
No. 1, Weatherford, Parker County	3.50	39.50	50.99	9.51	2.10	12410
Bridgeport, Wise County	12.50	36.26	49.12	14.62	2.11	12190
Bridgeport, Wise County	9.40	38.30	46.94	14.76	3.41	11196
Bridgeport, Wise County	9.20	37.40	47.37	17.23	2.00	11269
No. 7, Loving, Young County	18.00	37.70	49.00	13.30	1.35	12709
No. 7, Loving, Young County	18.50	38.90	45.52	15.58	2.36	12651
No. 7, Newcastle, Young County	11.00	38.45	42.68	18.87	4.24	10213
No. 7, Newcastle, Young County	7.00	41.38	43.20	15.42	2.13	10970

Ultimate Analyses of Texas Bituminous Coals of Pennsylvanian Age

No. of coal bed and mine	B. T. U.	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
No. 1, Thurber, Erath County	12526	71.78	5.35	10.75	2.17	1.98	7.97
No. 7, Jermyn, Jack County	10510	60.28	3.77	9.88	1.42	1.84	22.81
No. 7, Weatherford, Parker County	12410	70.91	4.85	9.29	3.34	2.10	9.51
Bridgeport, Wise County	11196	65.42	4.40	9.21	2.80	3.41	14.76
Bridgeport, Wise County	11209	63.80	4.67	11.40	2.90	2.00	15.23
No. 7, Newcastle, Young County	10213	58.25	4.17	12.35	2.12	4.24	18.87
No. 7, Newcastle, Young County	10970	61.21	5.09	12.15	3.00	2.13	15.42

Most of the Texas Pennsylvanian coal was used in producing steam in locomotives and manufacturing establishments. Smaller quantities were used for domestic fuels. Its use is now supplanted by oil and gas.

TRINITY CRETACEOUS COAL

Coal occurs along an arroyo about 1 mile southwest of Eagle Spring, on the northeast flank of the Eagle Mountains in southeastern Hudspeth County. The bed strikes N. 75° W. and dips 82° N. 15° E. In the old tunnel is exposed a thickness of 3 feet or more of coal. This coal, after being exposed to the weather in the old dump for thirty years or more, is still hard, dense, and shiny, somewhat metamorphosed, bituminous, and contains a large percentage of ash. No analysis is available. The complicated structure at the locality is apt to make the coal expensive to mine and the bed difficult to follow.

Referred doubtfully to the Trinity is an exposure of coal seen many years ago by the late W. F. Cummins. This is in the bank of an arroyo in the gravelly and sandy, largely alluvium-covered area about 8 miles northeast of Fort Hancock, Hudspeth County. The old prospect is now partly obliterated, and there is a possibility that the coal may be either Paleozoic or Jurassic in age.

UPPER CRETACEOUS COAL

Just as the Pennsylvanian coal of Texas is situated at the south end of the coal basin of that age in North America so is the Upper Cretaceous coal. The two being marginal, they have both thinner beds and coals higher in sulphur and ash than the average.

The Texas Upper Cretaceous coals are confined to the Rio Grande basin, being deposits of the Mexican depositional geosyncline. In this the waters shallowed after extensive marine deposits formed, the shallowing being caused by a filling of the basin with sediment, a halt in its gradual sinking, a lowering of sea-level, or a combination of the three. It appears more likely that the border areas of the geosyncline were elevated somewhat and, becoming subject to erosion, yielded sediment to the basin at a greater rate than formerly, while the site of deposition was itself either being uplifted or its previous subsidence at least halted by the general movements of uplift. Higher up the Rio Grande, in the Rim Rock country of

Presidio County, the Cretaceous sea had finally withdrawn from the region before coal deposits formed. Farther down the river, in the vicinity of Eagle Pass, the coal beds were overlain by extensive marine sediments, the highest marine Cretaceous of Texas. The coal in the southern Big Bend country of Brewster County is interbedded with marine sediments.

The Eagle Pass coal of Navarro Cretaceous age, is situated at the north end of a fairly extensive synclinal basin lying just east of the Front Range of the Mexican Cordillera in the Mexican state of Coahuila. In Mexico the coal has been mined at Sabinas, Esperanzas, Musquiz, and San Felipe. The coal is better in Mexico than in Texas, partly because it has there been subjected to more deformative movements and partly because it contains less inorganic sediment (ash). In former times much of the Mexican coal was exported to Texas and New Mexico. After washing and cleaning, the coal of the Sabinas basin is made into metallurgical coke. Natural gas piped from Texas to Monterrey has largely supplanted the use of coke in the smelters and other industrial plants there. Heavy Mexican crude oil has in large measure replaced coal on Mexican railroads. R. T. Hill states that the coal of the Sabinas basin in Mexico is by far the best in America except the true anthracites of Pennsylvania, ranking higher than the bituminous of the Appalachian region.

The Sabinas basin is farther southwest than the Eagle Pass-Piedras Negras basin and separated from it by a line of anticlinal uplift which in the Lomeria de los Peyotes brings up to the surface strata of Eagle Ford Cretaceous age. The Eagle Pass basin is really the northwestern end of a broad and very gentle syncline which plunges gently to the southeast and named by the writer the Nueces River syncline. The deformation has been considerably greater in the Sabinas synclinal basin, especially on its southwestern side where it flanks the Sierra Hermosa de Santa Rosa, and it is quite likely that it was the additional heat and pressure produced by the greater diastrophic forces which helped to improve the quality of the Sabinas coal over that at Eagle Pass.

On the Texas side of the river most of the coal lies east of a north-south line passing through the town of Eagle Pass. The trough of the syncline lies about 10 miles east of the town. Since the strata rise to the north, the coal outcrops around the rim of the syncline, especially on its west and northwest portions. The coal outcrop crosses the Rio Grande about 5 or 6 miles above Eagle Pass, continues in a northeastward direction for more than 8 miles to the north of the town, and then turns gradually to southeast of east. The eastward dip at Eagle Pass is at a fairly high rate. To the northwest, the coal divides into more numerous and thinner beds, intercalated in "bone" and shale, and the quality decreases. The coal probably thins to the east of Survey 145, Block 7, where sedimentation changed. The coal occurs in a nonmarine series of strata, 400 to 600 feet thick, known as the Olmos, and consisting of mainly lignitic and sandy shales with a few thin beds of sandstone. Although the earlier reports state there was a total thickness of coal ranging up to 7 feet, the later workings had an average of about 4 feet. In almost all cases there are a number of partings of "bone" and dirt, although at one place 6 feet of solid coal was reported. The mines were worked by the room and pillar method. In the Southern Pacific (Rio Bravo) mine a 2-foot bed of bituminous shale was used as fuel for the mine operations. The coal was used as fuel for the Southern Pacific locomotives and for industrial and domestic uses, mainly in San Antonio. Oil and gas now have supplanted the use of the coal.

Analyses of Navarro Upper Cretaceous Coal, Olmos Formation, Eagle Pass Field, Maverick County, Texas[3]

	As Received							Dry Basis						Ultimate						
No.	Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1514	9.40	32.70	39.80	18.10	100.00	1.35	10068	40.92	43.29	15.79	100.00									
1515	1.60	32.40	58.95	7.05	100.00	1.70	14020													
1516	2.80	32.80	55.55	8.85	100.00	0.80	13165													
1517	9.405							36.52	44.26	19.22	100.00	1.42	12317							
1518	4.20							38.15	33.76	28.09	100.00	0.74	10200	50.44	4.04	13.96	2.73	0.74		
1519	3.64							29.90	38.60	31.50	100.00	0.56	11000	51.23	3.73	11.78	1.20	0.56		
1520	6.91							41.00	39.56	19.44	100.00	1.28	12324							
1521	7.48	32.18	45.67	14.67	100.00		11530													
1522	6.43	32.43	42.88	18.26	100.00		11240													
1523	6.43	29.33	40.73	23.51	100.00		10146													
1524	8.83	32.68	44.89	13.60	100.00	0.90	10941	35.84	49.24	14.92	100.00	0.99	12001							
1525	6.68	30.94	42.94	17.44	100.00	0.90	10361	33.88	47.02	19.10	100.00	1.02	11455							
1526	7.98	30.00	40.06	21.96	100.00	0.94	9681	32.60	43.54	23.86	100.00	1.02	10520							
1527	11.11	28.53	42.26	18.10	100.00	1.06	9698	32.10	47.54	20.36	100.00	1.19	10910							
1528	6.76	27.04	33.66	32.54	100.00	1.79	8792	29.00	36.10	34.90	100.00	1.92	9429							
1529	5.20							32.13	41.92	25.95	100.00	0.91	10147							
1530	5.22							36.57	45.76	17.67	100.00	0.90	12165							
1531	4.50							37.70	42.30	20.00	100.00	2.10	11250							
1532	4.85							40.25	48.65	11.10	100.00	2.14	11695	67.38	4.83	13.08	1.47	2.14	11.10	
1533	8.20							39.20	57.73	3.07	100.00	1.80	12527	74.74	5.08	13.67	1.64	1.80	3.07	
1534	6.50							33.70	39.96	26.34	100.00	2.00	9636	55.44	4.14	9.56	2.52	2.00	26.34	
1535	5.40							38.00	44.49	17.51	100.00	1.30	11545	64.12	4.92	10.41	1.74	1.30	17.51	
1536	5.30							37.58	40.49	21.93	100.00	1.70	10807	60.01	4.63	9.93	1.80	1.70	21.93	
1537	5.70							35.50	39.16	25.34	100.00	1.80	10412	57.20	4.40	7.96	3.30	1.80	25.34	
1538	4.90							34.80	39.19	26.01	100.00	1.62	10380	56.08	4.00	10.98	1.31	1.62	26.01	
1539	5.20							36.42	43.07	20.51	100.00	1.56	10720	56.72	4.13	14.95	2.13	1.56	20.51	
1540	5.30							39.18	44.02	16.80	100.00	1.20	11412	62.08	4.20	14.00	1.72	1.20	16.80	
1541	9.10	29.20	38.90	22.80	100.00	1.39	10754	32.12	42.79	25.09	100.00	1.53	11831							
1542	8.70	32.90	38.20	20.20	100.00	1.26	9819													
1543	8.96	32.60	40.64	17.80	100.00	1.27	10084													
1544	9.40	32.70	39.80	18.10	100.00	1.35	10068													
1545	10.76	29.84	37.10	22.30	100.00	1.46	9008													
1546	8.16	32.26	36.98	22.60	100.00	1.24	9975	35.12	40.28	24.60	100.00	1.25	10860							

[3]Schoch, E. P., Chemical analyses of Texas rocks and minerals: Univ. Texas Bull. 1814, Analyses No. 1514–1546 inclusive, pp. 91–93 and 197–198, 1918.

Index[4] to Localities of Preceding Table

Anal. No.

1514. Maverick County. Upper Cretaceous coal from near Eagle Pass. U. T. B. 307, p. 26.

1515. Maverick County. Average of several coal analyses from the Dolch Mine near Eagle Pass. Anal. by the U. S. Bureau of Mines. U. T. B. 307, p. 26.

1516. Maverick County. Ditto as No. 1515, except that it was analyzed Sept. 14, 1911.

1517. Maverick County. From the Maverick County Coal Co., Eagle Pass. Anal. 1902 by O. H. P. and S. H. W. T. M. S. A. No. 1520.

1518. Maverick County. Sample of coal furnished the Austin White Lime Co., McNeill, Texas, by the Olmos Coal Co., Eagle Pass. Washed nut coal. Anal. 1911 by S. H. W. B. A. 42.

1519. Maverick County. Run-of-mine at works of the Austin White Lime Co., at McNeill. Furnished by the Olmos Coal Co., Eagle Pass. Anal. by S. H. W. 1911. B. A. 43.

1520. Maverick County. Sample of coal from Rio Bravo Coal Co., Eagle Pass. Anal. 1902 by O. H. P. and S. H. W. T. M. S. A. No. 1521.

1521., 1522., 1523. Maverick County. Sample from Olmos Coal Co., Eagle Pass. Analyses furnished by C. S. Plant, Superintendent Fuel Service, The Sunset-Central Lines. U. T. B. 307, p. 28.

1524. Maverick County. Lump coal from Olmos Coal Co., Eagle Pass. Anal. 1911 by S. H. W. B. A. 651.

1525. Maverick County. Washed egg coal from Olmos Coal Co., Eagle Pass. Without marks. Anal. 1913 by S. H. W. B. A. 652.

1526. Maverick County. Nut coal from Olmos Coal Co., Eagle Pass. Anal. 1913 by S. H. W. B. A. 653.

1527. Maverick County. Pea coal from the Olmos Coal Co., Eagle Pass, Texas. Anal. 1913 by S. H. W. B. A. 654.

1528. Maverick County. Coal from the International Coal Mines Co., Eagle Pass. Anal. 1913 by S. H. W. B. A. 697.

1529. Maverick County. From International Coal Mines Co., Eagle Pass. Sample "A." Screened nut. Received from W. B. Smith, of Austin, Texas. Anal. 1912 by S. H. W. B. A. 330.

1530. Maverick County. Screened egg coal from International Coal Mines Co., Eagle Pass. Sample "B." Anal. by S. H. W. B. A. 331.

1531. Maverick County. From Olmos Coal Co., Eagle Pass. Anal. 1912 by S. H. W. B. A. 332.

1532. Maverick County. From International Coal Mines Co., Eagle Pass. B. A. 4.

1533. Maverick County. "Special Sample" from International Coal Mines Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 5.

1534. Maverick County. From Olmos Coal Co. Marked: "For analysis and investigation." Anal. 1910 by S. H. W. B. A. 6.

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[4]For explanation of abbreviations used in list of localities, see footnote 14, p. 341.

1535. Maverick County. Washed egg coal from Olmos Coal Co., Eagle Pass. B. A. 31.

1536. Maverick County. Washed nut coal from Olmos Coal Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 32.

1537. Maverick County. Washed pea coal from Olmos Coal Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 33.

1538. Maverick County. Washed pea coal from Olmos Coal Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 50.

1539. Maverick County. Washed nut coal from Olmos Coal Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 51.

1540. Maverick County. Washed egg coal from Olmos Coal Co., Eagle Pass. Anal. 1910 by S. H. W. B. A. 52.

1541. Maverick County. Sample from Olmos Coal Co., Eagle Pass. Anal. 1915 by J. E. S. B. A. 2255.

1542. Maverick County. Washed egg coal from the Olmos Coal Co. Anal. 1915 by J. E. S. B. A. 2301.

1543. Maverick County. Washed nut coal from the Lamar Mine, Olmos Coal Co. Anal. 1915 by J. E. S. B. A. 2302.

1544. Maverick County. Washed pea coal from the Lamar Mine, Olmos Coal Co. Anal. 1915 by J. E. S. B. A. 2303.

1545. Maverick County. Washed coal, "Barleycorn," from the Lamar Mine, Olmos Coal Co. Anal. 1910 by J. E. S. B. A. 2304.

1546. Maverick County. Coal furnished The University of Texas power house by the Olmos Coal Co., of Eagle Pass. Washed egg. Car of coal donated to the University. Sampled March 1–5, 1915. Coal was out in rain for several days. Anal. by J. E. S. B. A. 2331.

The coal is high in percentage of ash and fairly high in percentage of sulphur. It has wide variation in B.T.U. value, from 8800 to 14,000. Some of the coal will coke.

The coal near the Rio Grande in Brewster and Presidio counties, Trans-Pecos Texas, occurs in the Rattlesnake (Aguja) formation and is probably of Navarro age, although it possibly belongs, at least in part, to an upper division of the Taylor.

Coal is known in several places in the southern Big Bend country of southern Brewster County, in a district extending from the Rosillos Mountains on the north to the mouth of Terlingua Creek on the south, and from the west side of the Carmen Range on the east to near Cigar Mountain on the west. The area is highly folded and faulted and is cut by igneous intrusions; some of the coal as a consequence resembles jet and has the composition of anthracite.

Analysis of two samples of the high-grade coal from 2 miles southwest of Strouds ranch gave the following results:[5]

	Per cent	*Per cent*
Moisture	2.44	1.47
Ash	4.23	1.93
Sulphur	.93	1.26
Volatile combustible matter	15.38	13.07
Fixed carbon	77.95	83.53

This coal is reported to be 18 inches in thickness. Immediately west of Slickrock Mountain a coal bed measures slightly under 20 inches thick. The same thickness of coal occurs at the Kimble pits on the south side of a hill at a point 2 miles north of Chisos Pen north of Rough Run. Analysis of this coal gave the following results:[6]

	Per cent
Moisture	4.68
Ash	16.60
Sulphur	.88
Volatile combustible matter	24.20
Fixed carbon	54.52

An 18-inch bed in the bottom of Cottonwood Creek at Chisos Pen has the following composition:[7]

	Per cent
Moisture	6.12
Ash	16.60
Sulphur	1.32
Volatile combustible matter	34.72
Fixed carbon	44.74

In the low ridges of the flats between Terlingua Abaja and the mouth of Terlingua Creek, about three-fourths of a mile south and a little west of the village, is an outcrop of 18 inches of coal. the weathered face of which has a composition as follows:[8]

	Per cent
Moisture	9.10
Ash	21.50
Sulphur	.90
Volatile combustible matter	37.38
Fixed carbon	32.02

[5]Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Texas: Univ. Texas Bull. 93 (Sci. Ser., Bull. 11), p. 95, 1907.

[6]*Idem.*, p. 96.

[7]*Ibid.*

[8]*Idem.*, p. 97.

Other outcrops are known, and further detailed exploration is warranted. Some of the coal has been used in the quicksilver mines, the wood fuel in the district being nearly exhausted and the use of fuel oil being handicapped by high cost of transportation.

In northwestern Presidio County, in the rough and now nearly inaccessible country lying west of and below the Rim Rock and to the east of the Rio Grande, and really a canyon of the Rio Grande, coal outcrops in the San Carlos anticlinal basin and to some extent farther north where the coal bed crosses the county line into western Jeff Davis County. In the northern area the coal dips from 3 to 5 degrees east and is crossed by a diabase dike. The domical uplift at San Carlos is broken by 18 known faults, the coal bed is cut in two places by a diabase dike, and the uplift is bounded on the west by a fault of 3000 feet displacement, the downthrow being to the west. There is a possibility that coal may be found in an area some miles farther south, where the strata are faulted and largely covered by a gravel sheet resting on a pediment cut on the bed rock.

The coal is in a sandstone and shale series overlying a section 375 feet in thickness composed of 250 feet of marl below and 126 feet of alternating shales and sandstone above, the two lower members containing marine Taylor fossils and the coal series being nonmarine and plant- and dinosaur-bearing. The horizon of the coal is 295 feet above the top of the marine beds. The coal formerly mined occurs in two beds, each about 2 feet thick and separated by an interval of about 2 to 4 feet of sandstone. There are several coal beds which vary from a few inches up to 3 or 4 feet in thickness. The main coal occurs in two zones each about 3 feet thick in several layers separated by clay and in some places by a lens of sandstone. The parting between the two coal zones is 8 feet in one section measured. Two 3-inch thick layers of coal separated by 3 feet of sandstone occur between 75 and 80 feet above the top of the marine strata.

Analyses of Upper Cretaceous Coal, San Carlos Area, Presidio County[9]

	As Received							Dry Basis						Ultimate						
No.	Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1547	1.09	36.61	35.29	24.01	100.00	-	-	-- -		-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1548	1.17	39.93	35.39	23.51	100.00	----	----	-----		- -	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1549	1.19	39.73	40.30	18.78	100.00	-----	-----	-----		-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1550	1.68	60.37	24.89	13.06	100.00	- -	-----	-----	---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1551	0.97	40.95	43.77	14.31	100.00	- -	-----	-----	- -	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1552	1.00	39.05	49.05	10.00	99.10	Trace	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1553	0.94	34.48	58.96	5.62	100.00	0.64		-----	-	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1554	4.60	39.20	50.10	6.10	100.00	0.62	12157	41.13	52.47	6.40	100.00	0.64	12757	-----	-----	-----	-----	-----	-----	-----
1555	4.90	32.80	43.04	19.26	100.00	0.85	9663	34.49	45.26	20.25	100.00	0.88	10161	-----	-----	-----	-----	-----	-----	-----
1556	2.47	34.84	32.36	30.33	100.00	1.61	8348	35.72	33.18	31.10	100.00	1.65	9585	-----	-----	-----	-----	-----	-----	-----
1557	5.67	14.58	4.66	75.09	100.00	0.32	-----	15.46	4.94	79.60	100.00	0.34	-----	-----	-----	-----	-----	-----	-----	-----

[9]Schoch, E. P., Chemical analyses of Texas rocks and minerals: Univ. Texas Bull 1814, Analyses No. 1547-1557 inclusive pp. 93-94 and p 198 1918.

Index[10] to Localities of Preceding Table

Anal. No.

1547.
1548.
1549.
1550.
1551.
Presidio County. Coal from the San Carlos field. Analyses, made by Dr. Peter Fireman, were made on samples from various parts of the seam as follows, respectively:

1547	Upper part of seam.
1548	Above binder.
1549	Below binder.
1550	Above clay, lower seam.
1551	Coal shaft.

U. T. B. 307, p. 30.

1552.
1553.
Presidio County. Coal from the San Carlos field. Reported in "Mineral Resources of the U. S.," 1893, p. 385. Analyses sent to the U. S. Geological Survey by Mr. R. E. Russell, Gen'l Mgr. of the San Carlos Coal Co., Pittsburgh, Pa. U. T. B. 189, p. 34.

1554. Presidio County. From upper vein in old cut, 300 yds. southeast of the Old Ingle tunnel, San Carlos coal field. Sample brought in by Dr. J. A. Udden. This sample does not coke. Anal. 1913 by S. H. W. B. A. 836.

1555. Presidio County. From upper vein in south bank of Arroyo, near southwest corner of Section 67, Block 3, of this county. Sampled by J. A. U. July, 1913. Anal. by S. H. W. B. A. 837.

1556. Presidio County. From lower coal Section 47, Block 3, D. & P. Ry. land. Sampled by J. A. U. Seam 18 inches thick. Anal. 1913 by S. H. W. B. A. 846.

1557. Presidio County. Coal near Stinking Spring, north area of outcrop of the San Carlos formation. Thickness of seam 20 inches. Sampled by J. A. U., July, 1913. Anal. by S. H. W. B. A. 847.

Mr. R. E. Russell, General Manager, San Carlos Coal Company, stated that coking tests of the coal had been made at Connellsville, Pennsylvania, and that 48-hour beehive coke gave carbon 93.7 per cent and ash, 6.30 per cent. Another analysis of the coke gave moisture 1.24 per cent; volatile and combustible matter, 4.96 per cent; fixed carbon, 66.93 per cent; and ash, 26.87 per cent. In 1895 a broad gauge railroad was constructed to San Carlos from Chispa siding on the Southern Pacific lines and a plant was built at San Carlos. Mine, plant, and railroad were subsequently abandoned.

EOCENE BITUMINOUS CANNEL COAL

The largest body of bituminous cannel coal in the United States, if not in the world, occurs in the Mount Selman formation of the

[10]For explanation of abbreviations used in list of localities, see footnote 14, p. 341.

Claiborne Eocene of the Santo Tomas field, Webb County, Texas. This is not a soft brown lignite like that found in the same strata farther northeast but is a low moisture coal almost as hard as anthracite, weathering like an ordinary bituminous coal and selling under contract guarantees of 12,500 B.T.U.'s on a dry basis. On distillation, this cannel coal yields a much higher proportion of oil at a low temperature or of gas at a high temperature than does ordinary bituminous coal, and these products may be in great demand in chemical industries. The coal behaves somewhat as if it had been soaked thoroughly in oil, for, when heated on top of a stove, oil will ooze out of it. The oil distilled out of cannel coal contains a large percentage of unsaturated hydrocarbons. The main disadvantages of Santo Tomas coal are the great cost of mining, because of thinness of beds and poor roof, and that bane of all Texas coals—high ash and sulphur content.

The cause of the low moisture content is obscure. It may be because the coal is cannel, or it may be because the coal is near enough to the Mexican Cordillera to have had its moisture driven off by the heat generated by mountain making. An exploration for the coal on the Mexican side of the Rio Grande failed to find it in workable thickness.

The Santo Tomas coal is bright, glossy and black, pitchlike, with a more brilliant lustre than most cannel coals. It is nearly as hard as splint coal and for that reason three-fourths of it is mined as lump. If free from pyrite it can be shipped long distances and stored for long periods without deterioration. It has a strong vertical cleavage in a N. 30° E. direction in the mine. It burns with a long flame and produces much smoke. Ashley[11] says: "In color, percentage of moisture, resistance to the weather, and heat value it compares favorably with the coals of Illinois, Indiana, Michigan, Iowa, and Missouri." Consequently it is the best coal in Texas.

A low temperature distillation test by the U. S. Bureau of Mines gave 52.2 gallons of 0.938 gravity oil which was non-liquid at 60° Fahrenheit and 5672 cubic feet of gas at 0° Centigrade and 760 millimeters pressure per ton of coal. The oil recovered was 20.2 per cent by weight of the coal. Water condensed was 9.5 per cent

[11]Ashley, G. H., The Santo Tomas cannel coal, Webb County, Texas: U. S. Geol. Surv., Bull. 691, p. 255, 1919.

by weight; the total loss of substance during the distillation process was 44.3 per cent. The oil as it comes from the still is suitable for ordinary burning and might find a use as flotation oil in metallurgy. Since it distills off at low temperature, it is full of unsaturated hydrocarbons, and for the production of gasoline, toluol, benzol, and other similar products, it would be necessary to resort to "cracking" or hydrogenation. A great amount of gasoline and lubricating oils can be made from this coal.

Tests on the gas by the Bureau of Economic Geology resulted as follows:

Yield per ton in cubic feet	7,320	6,600	7,147
Illuminants, per cent	5.5	5.4	5.4
Carbon monoxide, per cent	2.1	11.8	6.6
Hydrogen, per cent	42.0	40.0	43.6
Methane, per cent	43.9	39.0	36.2
Nitrogen, per cent	6.5	3.5	8.2
Specific gravity	0.385	0.428	0.424
Candle power	16.0	6.5	15.4
Observed B. T. U.'s per cubic foot	687	724	702
Calculated B. T. U.'s per cubic foot	630	702	667

There are two beds of coal, the San Pedro, which is a little more cannel-like, below and the Santo Tomas above. The interval between the two is about 90 feet. The San Pedro bed is in two benches, only the upper of which, averaging a little over 2 feet thick, is mined. It is more irregular than the upper coal, being absent in the vicinity of the Santo Tomas mine but present to the north and south. It is pinched out in a large area in the Dolores mine. The Santo Tomas bed is commonly from 24 to 36 inches thick and generally has a 2-inch parting near the middle. At the bottom there is an additional 2 to 14 inches of "bony" coal. From 14 to 20 feet above the coal there is a persistent bed, generally a "bony" coal, which varies from 6 to 12 inches thick. In the mines the coal dips from 2 to 3 degrees to the northeast. The room and pillar method was used in mining.

Analyses of Cannel Coal from Santo Tomas Field, Webb County[12]

			Proximate				Ultimate					
Mine or locality	Bed	Condition[a]	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Carbon	Hydrogen	Oxygen	Nitrogen	B. T. U.
Santo Tomas (?)	Santo Tomas	(?)	2.5	51.0	39.0	7.3	1.5					
25 miles northwest of Santo Tomas	Santo Tomas, upper bench	(?)	2.3	42.6	37.5	16.5	.8					
Santo Tomas (?)	Santo Tomas	(?)	2.2	48.6	36.1	12.9						
Santo Tomas (?)	Santo Tomas, lower bench	(?)	2.6	45.6	. 39.9	11.7						
Darwin mine	San Pedro, upper bench	(?)	2.7	49.9	37.5	9.7						
Darwin mine	San Pedro, upper part of lower bench	(?)	2.0	48.3	33.1	16.5						
Darwin mine	San Pedro, lower part of lower bench	(?)	2.3	49.3	38.0	10.2						
Santo Tomas	Santo Tomas	A	4.0	47.9	38.8	9.0	2.4	66.7	5.3	10.8	1.4	11,050
		C		50.0	40.5	9.4	2.5	69.5	5.5	11.5	1.3	12,570
Darwin	San Pedro	A	3.4	40.8	36.6	11.0	2.0	66.6	5.6	7.4	3.6	12,040
		C		50.7	37.9	11.3	2.1	69.0	5.9	7.7	3.7	12,470
Santo Tomas	Santo Tomas	C		47.5	39.1	13.3	2.0					12,470
San Jose	Santo Tomas	A	2.3	52.7	37.1	7.8	2.2	69.4	5.5	9.0	2.9	12,320
		C		54.0	37.9	8.0	2.2	71.0	5.6	10.0	3.0	12,600
San Jose	(?)	A	3.9	43.6	36.1	16.2	4.1					11,580
		C		45.4	37.6	16.9	4.3					12,070
Llave prospect	San Pedro	A	3.0	48.8	39.5	8.6	3.5					13,110
		C		50.3	40.7	8.9	3.6					13,510

[12]Ashley, G. H. The Santo Tomas cannel coal, Webb County, Texas: U. S. Geol. Surv., Bull. 691, pp 257–258, 1918.

[a]A, sample as received; C, moisture free; D, moisture and ash free.

Mine or locality	Bed	Condition[a]	Proximate: Moisture	Volatile Matter	Fixed Carbon	Ash	Ultimate: Sulphur	Carbon	Hydrogen	Oxygen	Nitrogen	B. T. U.
Santo Tomas	Santo Tomas	A	4.0	45.5	37.6	12.8	1.9					12,000
		C		47.3	39.1	13.3	2.0					12,470
(?)	Santo Tomas	A	2.6	46.4	38.9	11.9	2.3					12,340
		C		47.7	40.0	12.3	2.4					12,660
Santo Tomas	Santo Tomas	A	2.5	45.2	29.2	22.9	2.4					10,920
		C		46.9	30.0	23.6	2.5					11,190
Darwin	(?)	C		54.0	37.9	8.0	2.2	71.0	5.6	10.0	3.0	12,600
Santo Tomas	Santo Tomas	C		50.4	38.1	11.4	3.0	66.0	5.7	12.1	2.5	11,740
Cannel (Darwin), San Jose, and No. 3, average of 10 analyses run of mine	San Pedro	A	4.4	40.6	34.1	19.5	2.6					10,800
		C		42.5	36.8	20.5	2.8					11,400
		D		53.5	46.3		3.5					14,350
Santo Tomas, average of 12 analyses 4-inch lump	Santo Tomas	A	3.8	42.8	35.5	17.6	1.4					11,400
		C		44.6	37.0	18.3	1.5					11,850
		D		54.6	45.3		1.9					14,510
Santo Tomas, average of 3 analyses lump	Santo Tomas	A	4.2	42.8	37.2	15.9	1.9					11,550
		C		44.6	38.8	16.5	2.0					12,060
		D		53.4	45.7		2.5					14,440

[a] A, sample as received; C, moisture free; D, moisture and ash free.

Mine or locality	Bed	Condition[a]	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Sulphur	Ultimate: Carbon	Ultimate: Hydrogen	Ultimate: Oxygen	Ultimate: Nitrogen	B. T. U.
Santo Tomas, average of 5 analyses lump over 3-inch screen	Santo Tomas	A	3.9	44.5	36.9	14.4	1.7					11,870
		C		46.4	38.4	15.0	1.8					12,360
		D		54.5	45.2		2.2					14,560
Santo Tomas, shaft No. 1, mine sample	Santo Tomas	A	4.4	44.2	33.6	17.7	1.7					11,230
		C		46.2	35.2	18.5	1.7					11,750
		D		56.7	43.2		2.1					14,420
Dolores shaft, mine sample	Santo Tomas	A	4.4	46.0	30.5	19.0	2.0	59.3	5.7	12.6	1.1	11,070
		C		48.1	31.9	19.8	2.1	64.0	5.5	9.1	1.2	11,580
		D		60.1	39.8		2.7	77.4	6.8	11.4	1.5	14,450
Dolores shaft, mine sample	San Pedro	A	3.9	48.8	34.9	12.2	1.9	65.5	6.2	12.7	1.2	12,230
		C		50.9	36.4	12.8	2.0	68.3	6.0	9.5	1.3	12,740
		D		58.3	41.6		2.3	78.2	6.9	10.9	1.5	14,600
Hunt, mine sample, 30 feet in, weathered		A	3.6	31.6	20.9	43.7	1.3	38.9	4.3	10.8	.6	7,230
		C		32.8	21.7	45.4	1.4	40.4	4.1	7.9	.6	7,510
		D		60.1	39.8		2.5	74.1	7.5	14.5	1.2	13,760

[a]A, sample as received; C, moisture free; D, moisture and ash free.

EOCENE LIGNITES

Lignite beds are found in all stages of the Texas Eocene, but the most important deposits are in the Wilcox stage and the next most important in the Yegua formation of the Claiborne stage. The individual beds vary in thickness up to a maximum of at least 15 feet. Wilcox lignite occurs in Bowie, Cass, Marion, Harrison, Morris, Titus, Hopkins, Camp, Upshur, Wood, Rains, Van Zandt, Smith, Henderson, Panola, Shelby, Anderson, Freestone, Limestone, Leon, Robertson, Milam, Lee, Bastrop, Caldwell, Guadalupe, Wilson, Atascosa, Medina, Zavala, Dimmit, and Webb counties. Yegua lignite occurs in Angelina, Sabine, San Augustine, Newton, Jasper, Cherokee, Houston, Rusk, Nacogdoches, Brazos, Burleson, Wilson, Gonzales, Fayette, McMullen, Walker, Trinity, and Grimes counties. Lignite was mined in 1931 by the following companies:

Bastrop Lignite Coal Company, McDade, Bastrop County
John Belto, San Antonio; mine at Lytle, Medina County
Buniva Coal Company, Rockdale, Milam County
Chalmers Lignite Company, Bastrop, Bastrop County
Consumers Lignite Company, Alba, Wood County
Houston-Leon Coal Company, Crockett; mines at Evansville, Leon County, and near Lovelady, Houston County
Malakoff Fuel Company, McAlester, Oklahoma; mine at Malakoff, Henderson County
Morton Salt Company, Chicago, Illinois; mine in Rains County
G. H. Obel, Mingus, Palo Pinto County
O'Neal Lignite Coal Company, Texarkana, Titus County
Palestine Salt and Coal Company, Palestine, Anderson County
Sandow Lignite Company, McAlester, Oklahoma; mine at Rockdale, Milam County
Tredlow Lignite Company, McAlester, Oklahoma; mine in Henderson County
Waugh Coal Company, Calvin, Bastrop County
Workman-Cook Lignite Company, Winfield, Titus County

In the past, lignite was mined in the following counties which do not produce at present: Hopkins, Titus, Van Zandt, Fayette, Robertson, and Shelby.

Lignite from a surface-stripped mine at Malakoff is used as powdered fuel in the generation of electricity at the power plant of the Texas Power and Light Company at Trinidad, Henderson County.

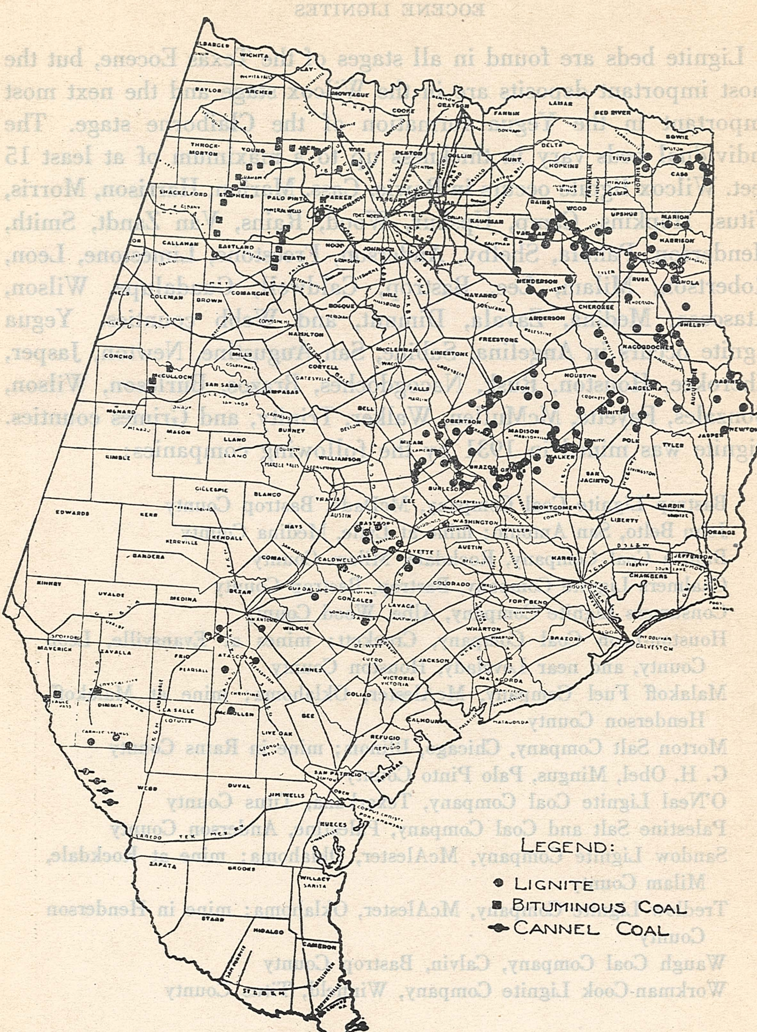

Fig. 19. Map showing the principal outcrops and mine explorations of seams of coal and lignite in east-central Texas. Largely after E. T. Dumble. From University of Texas Bulletin 44, page 138.

The Wilcox lignites in the southwesternmost part of their outcrop in Texas appear to have changed over to bituminous grade as they near the Mexican mountain ranges, where conceivably they have been subjected to heat and pressure developed by the mountain-making movements. The Santo Tomas coal of Webb County has already been considered under the heading of bituminous coal. Five borings on the I. T. Pryor ranch in Zavala County showed thicknesses of coal as follows: 16 feet, 15 feet, 4 feet, 3 feet, and 4 feet. Thirteen air-dried samples of coal from these borings were analyzed by David Hancock, Birmingham, Alabama, the average composition being as follows:

	Per cent
Moisture	6.11
Volatile matter	37.30
Fixed carbon	40.99
Ash	15.50
Sulphur	1.97
B. T. U.'s (dry basis)	11,231

Another sample from one of the borings analyzed by Herman Nestor of San Antonio gave the following results:

	Per cent
Moisture	15.32
Fixed carbon	53.00
Ash	11.05
Sulphur	3.02
B. T. U.'s	11,530

Lignite mixed with clay or shale is used in the manufacture of saggers and porous brick and tile products, the porosity of which is produced by the lignite being burned out during firing. Powdered lignite is being used also as a filtering medium. Lignite, mixed with clay, is burned to form railroad ballast.

Analyses of Texas Lignites[13]

	As Received							Dry Basis						Ultimate						
No.	Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1239	12.50	36.37	37.67	13.46	100.00															
1240	13.285	59.865	18.525	8.325	100.00															
1241	25.00	18.20	43.80	13.00	100.00	1.23	8105	24.27	58.40	17.33	100.00	1.64	10131							
1242	34.82	19.73	34.62	10.80	100.00	1.26	7860	26.50	58.90	14.60	100.00	1.73	10598							
1243	24.00	36.07	32.97	6.96	100.00	0.62	9002	47.46	43.38	9.14	100.00	0.82	11845							
1244	16.40	37.04	32.35	14.21	100.00	3.10	8599	44.30	36.70	17.00	100.00	3.71	10286							
1244a	6.50	30.70	8.30	54.50	100.00			32.83	8.88	58.29	100.00									
1245	35.40	36.88	21.22	6.50	100.00	0.94							12166							
1246	37.26							50.76	39.54	9.70	100.00	0.90	10226							
1247	10.00							51.75	26.50	21.75	100.00	2.50	9036							
1248	24.50							47.34	40.66	12.00	100.00	0.80	10930							
1248a	32.50	28.96	32.18	6.36	100.00		7325	42.90	47.68	9.42	100.00		10852							
1249	23.64	43.15	23.15	9.70	100.00	2.03	8104	56.98	30.32	12.70	100.00	2.66	10613							
1250	14.60	18.00	8.60	58.60	100.00			21.08	10.07	68.85	100.00									
1251	13.68							55.20	29.84	14.96	100.00	0.54	11780	53.49	4.45	24.82	1.74			
1252	4.38	38.97	43.03	13.62	100.00	4.14														
1253	4.13	39.89	40.40	15.58	100.00	5.22														
1253a	18.04	44.91	35.82	1.23	100.00	1.77	10794	54.80	43.70	1.50	100.00	2.16	13170							
1254	13.06	43.18	36.59	7.17	100.00	5.70														
1255	8.15	29.06	39.73	23.08	100.00	1.33														
1255a	20.74	37.26	28.60	13.40	100.00		8416	47.01	36.09	16.90	100.00		10618							
1256	15.80	39.42	39.78	5.00	100.00															
1257	7.00	53.70	32.55	6.75	100.00	0.89														
1258	5.40	34.65	27.70	33.25	100.00	1.33														
1259	8.15	43.55	42.50	5.80	100.00	3.37														

[13]Schoch, E. P., Chemical analyses of Texas rocks and minerals: Univ. Texas Bull. 1814, Analyses No. 1239–1462, pp. 75-88 and 169-195, 1918.

1260	16.42	18.80	28.75	36.03	100.00															
1261	31.12							49.28	17.82	32.90	100.00	1.34	9709	56.67	4.70	18.14	1.33			
1262	1.20	33.42	16.58	48.80	100.00	5.77	8416	33.83	16.78	49.39	100.00	5.84	8516							
1263	19.82							45.42	35.19	19.39	100.00									
1264	27.80							53.05	18.14	28.81	100.00									
1265	33.50							50.30	27.40	22.30	100.00									
1266	39.00							58.50	34.50	7.00	100.00	2.40						2.40	7.00	
1267	38.50							56.52	32.48	11.00	100.00		11110							
1268	46.30							54.50	33.30	12.20	100.00	2.70	11222	59.82	5.44	18.26	1.58	2.70	12.20	100.00
1269	38.60																			
1270	46.00							49.04	41.22	9.74	100.00									
1270a	31.26	23.24	19.80	25.70	100.00		6000	33.81	28.80	37.39	100.00		8722							
1270b	31.50	29.94	28.56	11.00	100.00		7559	42.25	41.69	16.06	100.00		11035							
1271	26.90	33.80	29.40	9.90	100.00	1.65	7714	46.24	40.22	13.54	100.00	2.25	10566							
1272	23.47	31.83	26.50	18.20	100.00	1.92	7481	41.59	34.62	23.79	100.00	2.51	9775							
1273	25.64	37.16	29.90	7.30	100.00	1.24	9195	49.97	40.21	9.82	100.00	1.66	12365							
1274	27.40	26.53	36.71	9.36	100.00	1.39	7977	36.54	50.56	12.90	100.00	1.92	10988							
1275	27.20	33.23	31.13	8.44	100.00	1.40	8056	45.64	42.76	11.60	100.00	1.92	11066							
1276	31.00	32.09	30.29	6.62	100.00	0.86	7560	46.50	43.90	9.60	100.00	1.24	10957							
1277	23.00	34.40	32.59	10.01	100.00	0.95	7903	44.68	42.32	13.00	100.00	1.24	10264							
1278	25.00	34.47	33.25	7.28	100.00															
1279	25.00	33.59	33.39	8.02	100.00															
1280	22.50							54.70	36.20	9.00	100.00	0.07	10600							
1281	16.50	39.00	31.30	13.20	100.00	1.69	8338	46.71	37.48	15.81	100.00	2.02	9986							
1282	12.60	40.20	26.40	20.80	100.00	2.27	8338	46.00	30.21	23.79	100.00	2.59	9540							
1282a	30.60	30.99	30.42	8.00	100.00	1.23	7793	44.64	43.83	11.53	100.00	1.77	11229							
1283	33.87	45.88	3.41	16.84	100.00							0.68	9790							
1284	10.20	39.92	44.13	5.75	100.00															
1285	22.92	50.28	21.66	5.14	100.00															
1286	23.10	29.96	30.50	16.44	100.00	1.38	7481	38.96	39.67	21.37	100.00	1.80	9728							
1287	36.64							44.70	42.63	12.67	100.00	0.64	10605	57.66	4.40	23.70	1.53	0.64	12.67	100.00
1288	34.00							39.50	49.38	11.12	100.00	1.01	11680	62.59	4.84	18.12	2.32			
1289	17.80							40.10	38.30	21.60	100.00	1.26	9967							
1290	36.16	33.16	19.93	10.75	100.00							0.40	10994							
1291	41.50	28.90	23.17	6.42	100.00	1.38	6605	49.40	39.60	11.00	100.00	2.37	11291							

	As Received							Dry Basis						Ultimate						
No.	Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1292	30.70	29.04	29.66	10.60	100.00		6936	41.90	42.80	15.30	100.00		10009							
1293	32.58	37.02	19.56	10.84	100.00	0.56														
1294	33.50	39.50	16.25	10.75	100.00	0.56	7142													
1295	34.70	33.23	21.87	11.20	100.00	0.76	7056													
1296	6.90	16.07	8.79	68.24	100.00	1.46		17.26	9.44	73.30	100.00	1.57								
1297	12.60	44.75	33.90	8.75	100.00	0.63														
1298	16.50	36.07	37.17	10.26	100.00	1.66	9774													
1299	16.00							53.54	37.16	9.30	100.00									
1300	1.80							62.22	22.78	17.00	100.00									
1301	12.80							56.06	34.94	9.00	100.00									
1302	2.60							62.32	27.58	11.10	100.00									
1303	20.00							58.62	33.68	7.70	100.00	1.46	11020							
1304	15.00							51.93	38.07	10.00	100.00	0.60	11380							
1305	25.80							45.00	43.00	12.00	100.00	1.40	10980							
1306	15.71							45.20	46.30	8.50	100.00									
1307	28.20							44.38	39.28	15.84	100.00	1.31	10006							
1308	33.00	28.90	29.40	9.70	100.00	0.98	8027	43.13	42.39	14.48	100.00	1.48	11980							
1309	33.00	27.84	30.26	9.00	100.00	0.88	8057	41.40	45.16	13.44	100.00	1.48	12026							
1310	31.50	27.60	34.20	6.70	100.00	0.82	8260	40.29	49.93	9.78	100.00	1.20	12058							
1311	24.60	32.60	32.70	10.10	100.00	0.62	7760	43.24	43.36	13.40	100.00	0.82	11221							
1312	34.80	29.28	30.25	5.67	100.00	1.55	7519	44.90	46.40	8.70	100.00	0.84	11533							
1313	26.50	28.96	28.81	15.73	100.00	1.11	6528	39.40	39.20	21.40	100.00	1.51	8884							
1314	19.80	35.74	35.00	9.46	100.00	0.90	8494	44.57	43.64	11.80	100.00	1.12	10598							
1315	30.80	30.24	31.76	7.20	100.00	0.82	7496	43.70	45.90	10.40	100.00	1.19	10832							
1316	23.04	33.72	35.20	8.04	100.00	1.29	8697	43.82	45.74	10.44	100.00	1.68	11275							
1317	30.20	28.04	30.18	11.58	100.00		7538	40.17	43.24	16.59	100.00		10800							
1318	27.30	31.28	30.92	10.50	100.00		7403	43.02	42.54	14.44	100.00		10183							

1319	27.10	30.70	28.80	13.40	100.00		6546	42.11	39.51	18.38	100.00	2.71	8980							
1319a	27.80	31.80	31.70	8.70	100.00	1.19	8808	44.04	43.91	12.05	100.00	1.65	12196							
1320	9.00	34.62	43.84	12.54	100.00	1.41	7658	38.04	48.18	13.78	100.00	1.54	8416							
1321	12.00	42.00	32.00	13.00	100.00															
1322	35.30	36.33	28.85	7.52	100.00							0.93	12215							
1323	34.29	40.31	18.50	6.90	100.00							1.20	11470							
1324	31.67	24.81	26.49	17.03	100.00	3.55														
1325	32.92	27.42	27.08	12.58	100.00	1.46	6840													
1326	27.39	35.07	28.16	9.38	100.00	0.88	7485													
1327	28.34	41.49	21.63	8.54	100.00	0.87	7846													
1328	28.20							45.78	39.15	15.07	100.00									
1329	32.00	29.77	29.20	9.03	100.00	1.24	7842	43.78	42.94	13.28	100.00	1.65	11533							
1330	32.79	37.09	22.91	7.21	100.00							1.18	11551							
1331	34.72	34.26	22.73	8.29	100.00							1.04	11792							
1332	32.27	44.30	15.26	8.17	100.00							2.31	10901							
1333	33.63	46.78	7.45	12.14	100.00							0.99	11088							
1334	31.52	44.49	17.48	6.51	100.00							0.93	11750							
1335	29.07	28.96	24.47	7.60	100.00							3.29	10489							
1336	24.20	36.28	30.62	8.90	100.00	1.14	7684	47.87	40.39	11.74	100.00	1.14	7684							
1337	13.41	37.03	39.43	10.13	100.00	1.36	9582	42.76	45.54	11.70	100.00	1.57	11066							
1338	29.60	31.50	30.24	8.66	100.00	1.00	7593	44.74	42.95	12.30	100.00	1.37	10785							
1339	16.73	36.09	35.36	11.82	100.00	1.26	8695	43.34	42.46	14.20	100.00	1.51	10442							
1340	30.34							49.00	44.00	7.00	100.00	0.87	9957	60.47	4.76	25.20	1.70	0.87	7.00	100.00
1341	30.20							47.60	41.31	11.09	100.00	0.98	[illegible]	61.20	4.05	20.58	2.09	0.98	11.09	100.00
1342	32.12							50.52	39.20	10.28	100.00	1.20	9855	59.16	3.82	22.96	2.58	1.20	10.28	100.00
1343	20.64							45.66	41.12	13.22	100.00	0.80	10410	58.81	4.46	20.21	2.50	0.80	13.22	100.00
1344	12.60							51.20	38.78	10.02	100.00	0.72	11182	64.20	4.56	19.30	1.20	0.72	10.02	100.00
1345	36.01	27.95	28.66	7.38	100.00	0.77	7132													
1346	35.56	27.91	27.49	8.04	100.00	0.75														
1347	31.06	27.67	33.39	7.88	100.00	0.99	7870													
1347a	27.30	27.40	33.55	11.10	100.00	0.65		40.33	42.93	15.93	100.00	0.80								
1348	4.45	52.05	15.15	28.35	100.00															
1349	0.86	32.64	63.64	2.86	100.00	0.25														
1349a	30.24	30.22	32.68	6.86	100.00	3.73	8494	43.32	46.82	9.87	100.00	5.38	12176							
1350	29.86	51.00	10.00	9.14	100.00							0.91	11305							

No.	As Received: Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Dry Basis: Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Ultimate: Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1351	34.32	35.95	30.93	8.80	100.00	0.95	7214	—	—	—	—	—	—	—	—	—	—	—	—	—
1352	33.50	26.06	30.38	10.06	100.00	0.97	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1353	31.00	34.02	27.88	7.10	100.00	0.65	8500	44.55	45.15	10.30	100.00	0.85	11140	—	—	—	—	—	—	—
1354	29.40	32.12	33.89	4.59	100.00	0.73	8110	45.50	48.00	6.50	100.00	1.04	11487	—						—
1355	29.40	29.51	32.01	9.08	100.00	1.29	10536	41.80	45.34	12.86	100.00	1.29	10536	—			—			—
1356	35.60	32.24	27.46	4.70	100.00	—		50.06	42.74	7.30	100.00	1.19	11455	—	—				—	—
1357	31.40	29.36	31.25	7.99	100.00	—		42.80	45.57	11.64	100.00	1.16	11019	—						—
1358	30.60	30.19	34.07	5.14	100.00	—		43.50	49.10	7.40	100.00	1.13	11674	—	—		—	—	—	—
1359	29.80	34.54	29.69	5.97	100.00	0.77	8129	49.20	42.30	8.50	100.00	1.10	11580	—			—	—		—
1360	25.80	34.40	31.20	8.60	100.00	1.24	8416	—	—	—	—	—	—	—			—			—
1361	20.34	36.76	31.70	11.20	100.00	1.24	9118	—		—	—	—	—	—			—			—
1362	21.20	32.80	32.10	13.90	100.00	1.37	8806	—		—	—	—	—	—		—	—		—	—
1363	18.90	35.52	30.18	15.40	100.00	1.37	8775	—	—	—	—	—	—	—	—	—	—	—		—
1364	16.50	31.50	24.90	27.10	100.00	1.37	7995	—	—	—	—	—	—	—	—	—	—	—	—	—
1365	24.20	34.40	30.90	10.50	100.00	1.24	8884	—	—	—	—	—	—		—	—	—	—	—	—
1366	26.90	32.00	32.80	8.30	100.00	1.24	8962	—	—	—	—	—	—	—	—	—	—	—	—	—
1367	20.70	33.10	29.60	16.60	100.00	1.24	8572	—	—	—	—	—	—	—	—	—	—	—	—	—
1368	20.10	31.60	31.90	16.40	100.00	1.24	9507	—	—	—	—	—	—	—	—	—	—	—	—	—
1369	18.30	29.40	25.90	26.40	100.00	1.37	7949	—	—	—	—	—	—	—					—	—
1370	10.30	38.70	37.60	13.40	100.00	1.24	10209	—			—	—	—	—			—		—	—
1371	14.30	39.10	36.10	10.50	100.00	1.37	10162	—							—	—				—
1372	15.10	37.30	35.80	11.80	100.00	1.37	9694	—	—	—	—	—	—		—					—
1373	10.90	35.50	35.30	18.30	100.00	1.37	9663	—	—		—	—	—	—	—	—	—		—	—
1374	12.54	31.36	29.50	26.60	100.00	1.37	8650		—			—	—	—		—	—		—	—
1375	11.50	43.90	38.04	6.56	100.00	2.22	11221	49.60	42.90	7.41	100.00	2.51	12680				—	—	—	—
1376	13.51	45.36	32.44	8.69	100.00	0.88											—	—	—	—
1377	15.701	4.105	79.137	1.057	100.00	—		—			—	—	—	—	—	—	—	—	—	—

1378	31.96	39.53	23.05	5.46	100.00							1.46	11837							
1379	14.45	38.82	35.18	11.55	100.00	0.93														
1380	28.00							24.20	14.42	61.38	100.00	2.40	5220							
1381	21.50									65.50										
1382	13.20	53.70	29.80	3.30	100.00	2.99	11424	61.87	34.33	3.80	100.00	3.45	13160							
1383	31.24							58.60	30.64	10.76	100.00	1.05	9782							
1384	34.50	29.96	29.04	6.50	100.00	1.28	7403	45.74	44.34	9.92	100.00	1.95	11298							
1385	11.40							48.30	38.10	13.60	100.00	1.00								
1386	25.20							50.02	34.78	15.20	100.00	1.60	10200							
1387	22.50							46.50	31.12	22.38	100.00	1.50	9850							
1388	27.20							56.18	37.20	6.62	100.00	0.65	10540	61.42	5.12	24.63	1.556	0.65	6.62	100.00
1389	13.73	45.95	37.22	3.10	100.00															
1390	19.80	33.38	25.32	21.50	100.00	2.81	5299	41.62	31.57	26.81	100.00	3.50	6607							
1391	30.30	25.70	24.50	19.50	100.00	3.02	8857	36.87	35.15	27.98	100.00	4.34	9842							
1392	35.60							70.21	18.02	11.77	100.00	0.73	11751							
1393	34.23							63.47	30.19	6.34	100.00	0.86	11694							
1394	24.50	31.30	38.00	6.20	100.00												0.98			
1395	27.00	35.90	28.70	8.40	100.00	1.92	7512	49.18	39.31	11.51	100.00	2.63	10290							
1396	29.20							52.14	38.22	9.64	100.00	0.81	10510	61.14	4.75	21.95	1.71	0.81	9.64	100.00
1397	27.50							48.54	37.65	13.81	100.00	1.00	9709	59.58	4.29	19.99	1.33	1.00	13.81	100.00
1398	15.00							51.30	38.48	10.22	100.00	1.10	10340	58.20	4.21	24.65	1.62	1.10	10.22	100.00
1399	25.85	35.58	31.30	7.27	100.00	0.54	7974	47.99	42.21	9.80	100.00	0.73	10754							
1400	27.51	33.42	28.12	10.95	100.00	0.62	7739	46.10	38.80	15.10	100.00	0.85	10676							
1401	26.54	30.85	32.71	9.90	100.00	0.68	7728	42.00	44.52	13.48	100.00	0.92	10520							
1402	24.95	32.21	32.06	10.78	100.00	0.70	7785	42.92	42.72	14.36	100.00	0.95	10598							
1403	28.86	35.96	27.26	7.92	100.00	0.50	7996													
1404	31.34	41.18	18.96	8.50	100.00	0.57														
1405	33.71	29.25	29.76	7.28	100.00	0.53	7348													
1406	33.98	31.01	27.33	7.68	100.00	0.56														
1407	36.80	28.86	28.09	6.25	100.00	0.53	7101													
1408	34.87	29.80	27.69	7.64	100.00	0.50														
1409	33.85	27.50	31.35	7.30	100.00	0.51	7497													
1410	24.80	32.20	29.20	13.80	100.00	1.10	8105	42.83	38.83	18.34	100.00	1.46	10780							
1411	22.30	33.80	24.60	19.30	100.00	1.37	8213	43.50	31.66	24.84	100.00	1.76	10570							
1412	19.90	33.36	30.04	16.50	100.00	1.24	8385	41.90	37.50	20.60	100.00	1.54	10470							

No.	As Received: Moisture	Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Dry Basis: Vol. and comb. matter	Fixed carbon	Ash	Total	Sulphur	B. T. U.	Ultimate: Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Total
1413	19.70	34.06	29.94	16.30	100.00	1.64	8260	42.41	37.29	20.30	100.00	2.04	10290							
1414	16.60	29.90	28.50	25.00	100.00	1.33	7278	35.85	34.16	29.99	100.00	1.81	8727							
1415	23.36	30.14	31.40	15.10	100.00	1.24	8027	26.94	30.66	30.30	—	—	—							
1416	26.94	30.66	30.30	12.10	100.00	1.85	8260	—	—	—	—	—	—							
1417	27.56	30.94	29.60	11.90	100.00	1.78	8027	—	—	—	—	—	—							
1418	27.70	30.50	29.30	12.50	100.00	1.85	7559	—	—	—	—	—	—							
1419	22.40	29.50	28.80	19.30	100.00	1.58	7247	—	—	—	—	—	—							
1420	21.40	35.66	31.44	11.50	100.00	1.10	8572	—	—	—	—	—	—							
1421	22.60	32.20	30.70	14.50	100.00	1.03	8104	—	—	—	—	—	—							
1422	26.70	32.10	28.90	12.30	100.00	1.35	7824	—	—	—	—	—	—							
1423	23.12	33.64	29.04	14.20	100.00	1.35	7948	—	—	—	—	—	—							
1424	22.50	31.24	29.36	16.90	100.00	1.20	7637	—	—	—	—	—	—							
1425	23.46	33.60	32.64	10.30	100.00	1.10	8343	—	—	—	—	—	—							
1426	16.60	35.60	34.00	13.80	100.00	0.96	8837	—	—	—	—	—	—							
1427	17.46	38.44	28.50	15.60	100.00	1.24	8198	—	—	—	—	—	—							
1428	19.70	34.00	33.00	13.30	100.00	1.10	8650	—	—	—	—	—	—							
1429	20.76	32.64	31.20	15.40	100.00	1.24	8182	—	—	—	—	—	—							
1430	16.26	32.64	32.00	19.10	100.00	1.37	8214	—	—	—	—	—	—							
1431	18.90	35.40	35.20	10.50	100.00	0.96	9118	—	—	—	—	—	—							
1432	20.50	34.36	33.74	11.40	100.00	1.24	8712	—	—	—	—	—	—							
1433	16.90	35.60	35.95	11.60	100.00	1.24	9090	—	—	—	—	—	—							
1434	14.10	36.50	36.60	12.80	100.00	1.24	9585	—	—	—	—	—	—							
1435	12.14	34.06	34.70	19.10	100.00	1.24	8775	—	—	—	—	—	—							
1436	8.37	25.93	36.40	29.30	100.00	1.68	8104	28.30	30.72	31.98	100.00	1.83	8844							

Ultimate Analyses of Texas Lignite

No.	County	Moist.	Carbon	Hydro.	Oxygen and Nitro.	Ash	Sulphur
1437	Anderson	....	53.06	4.06	24.12	17.74	1.02
1438	Bowie	10.67	59.84	3.10	26.97	9.10	1.00
1439	Cherokee	....	66.67	3.81	22.08	5.83	1.64
1440	Gregg	12.00	60.79	4.96	23.68	9.27	0.88
1441	Harrison	13.35	66.32	3.95	21.56	8.97	2.20
1442	Houston	....	63.09	3.64	22.56	9.68	1.03
1443	Lee	16.50	62.48	3.21	20.80	11.56	1.95
1444	Leon	....	63.60	4.08	24.02	7.79	0.55
1445	Medina	13.25	60.92	2.57	25.34	9.10	1.47
1446	Milam	....	60.93	4.12	22.27	11.36	1.32
1447	Milam	17.75	62.50	5.45	20.84	7.54	0.97
1448	Milam	18.25	64.50	5.37	20.76	8.56	0.81
1449	Morris	8.55	59.87	4.70	24.35	8.66	2.42
1450	Rains	....	57.04	4.01	24.48	13.35	1.11
1451	Rains	....	59.32	2.80	20.27	16.63	0.98
1452	Robertson	....	58.16	4.46	13.11	12.77	1.50
1453	Robertson	16.40	65.14	5.29	19.28	9.21	1.15
1454	Rusk	16.63	58.93	4.20	22.14	10.09	4.64
1455	San Augustine	....	61.12	3.32	24.53	7.75	3.39
1456	Smith	9.83	57.40	3.60	23.31	14.74	0.95
1457	Webb (outcrop)		59.28	3.29	16.98	17.56	0.89
1458	Wood	10.85	56.33	4.29	24.13	14.39	0.84
Average		13.67	60.98	4.01	22.16	11.01	1.48

Ash from Wood County Lignite

No.	Silica	Alumina	Ferric Oxide	Lime	Magnesia	Sulphuric Acid	Total
1459	45.03	19.14	5.15	22.95	0.80	8.04	101.11
1460	46.88	24.35	2.23	15.90	0.82	9.15	99.33
1461	46.64	23.46	6.58	19.57	0.87	4.31	101.43
1462	35.64	27.32	6.60	21.45	0.46	10.16	101.63

Index[14] to Localities of Preceding Table

ANALYSTS

D. McN. P. = Drury McNeil Phillips.
E. L. P., Jr. = E. L. Porch, Jr.
J. A. U. = Johan August Udden.
J. E. S. = John Edward Stullken.
J. H. H. = J. H. Herndon.
L. E. M. = L. E. Magnenat.
O. H. P. = O. H. Palm.
P. S. T. = P. S. Tilson.
S. H. W. = S. H. Worrell.
W. B. P. = William B. Phillips.

[14]The abbreviations for analysts and sources of analyses given here are also used in lists of localities appearing on pp. 320, 325, and 462.

SOURCES OF ANALYSES

B. A.=Bureau Analysis: Analyses taken from the office files of the University of Texas Bureau of Economic Geology. Those in which the numbers are preceded by capital "C" are from the files of the Bureau of Industrial Chemistry, *e.g.*, B. A., C135.

T. A. S.=Texas Academy of Science (Proceedings).

T. G. S. A R.=Texas Geological Survey Annual Report.

T. M. S. A. No.=Texas Mineral Survey Analyses No. taken from the office files of the University of Texas Mineral Survey.

U. T. B.=University of Texas Bulletin (official series).

1239. Angelina County. Lignite sample, almost like pitch coal, from bed of Angelina River. U. T. B. 365, p. 57.

1240. Atascosa County. Lignite from the Kinny mine, adjoining the Kirkwood mine, 18 miles southwest of San Antonio. T. G. S. A. R. 1892, p. 185.

1241. Atascosa County. Lignite from mines at Poteet, and sent in by the Poteet Sand and Coal Co., Poteet. Sample exposed to the air and somewhat dry. Analyzed 1913 by S. H. W. B. A. 599.

1242. Atascosa County. From mines at Poteet. Fresh sample sent in by Poteet Sand and Coal Co., Poteet. Analyzed 1913 by S. H. W. B. A. 600.

1243. Atascosa County. From J. A. Burger, San Antonio, Texas. From ranch near Poteet, 30 to 40 feet under cover, thickness of vein 4–5 feet. Analyzed 1913 by S. H. W. B. A. 936.

1244. Atascosa County. From a vein on Franklin ranch, about 15 miles southwest of Christine. Sample submitted to Univ. Bur. Ec. Geol. for analysis Jan., 1914. Analyzed by S. H. W. B. A. 1137.

1244a. Atascosa County. From lands between Jourdanton and Charlotte. Sample sent by Jourdan Campbell. Analyzed 1917 by J. E. S. No. C514.

1245. Bastrop County. Lignite from Glenn-Belto Mine, Bastrop. T. M. S. A. No. 1537.

1246. Bastrop County. From Independence Mining Co., Phelan, Bastrop Co. Analyzed 1910 by S. H. W. B. A. 21.

1247. Bastrop County. Outcrop near Clopton Switch, 8 miles south of Elgin. Analyzed 1912 by S. H. W. B. A. 175.

1248. Bastrop County. Lignite from Independence Mining Co., Phelan. Analyzed 1911 by S. H. W. B. A. 192.

1248a. Bastrop County. From Sayer Mine owned by F. L. Denison, McDade. Sent by State Purchasing Agent, Jan., 1918. Analyzed by J. E. S. No. C623.

1249. Bexar County. Lignite from near Cassin Station, on the S. A. U. & G. Ry. Outcrop on Medina River, 40–45 ft. below surface. Seam 4½ ft. thick. Sent in by Dr. Bredlick, Pleasanton, Texas. Analyzed 1914 by J. E. S. B. A. 1477.

1250. Bexar County. Lignite from ½ mile north from outcrop of sample No. 1249; drill sample, 164 ft. below surface; seam 14 inches thick. Sent in by Dr. Bredlick of Pleasanton. Analyzed 1914 by J. E. S. B. A. 1478.

1251. Bowie County. Lignite sample received from R. W. Rodgers, Texarkana. Analyzed 1911 by S. H. W. B. A. 38.

1252. Burnet County. The exact locality of these samples not stated. Analyzed by Dr. E. Everhardt of the Univ. of Texas. T. A. S. III, p. 25.

1253. Burnet County. Ditto as for No. 1252.

1253a. Brown County. Black lignite showing carbonized woody fiber. Sample sent by D. F. Johnson, Brownwood, 1913. Analyzed by J. E. S. B. A. 695.

1254. Caldwell County. Sample of glance coal from Burdett Wells exposure. Sample sent to Lab. of T. G. S. by S. J. McDowell. T. G. S. A. R. 1892, p. 184.

1255. Caldwell County. Brown coal, massive and laminated, taken at Burdett Wells exposures. Sample sent to Lab. of T. G. S. by S. J. McDowell. T. G. S. A. R. 1892, p. 184.

1255a. Camp County. From boundary of Wood and Camp counties, 1 mile from Newsome. Depth of mine at foot of hill 33 ft. Vein is 5½ ft. thick. Another vein 20 ft. deeper is 4 or 5 ft. thick. Sample sent by Hatfield and Clinton, who own 500 acres of this lignite. Analyzed 1918 by J. E. S. No. C646.

1256. Cass County. Sample of lignite from Stone Coal Bluff, northeastern part of county, 12 ft. thick. U. T. B. 365, p. 89.

1257. Cherokee County. Lignite, light to dark brown in color, laminated, taken 6 miles south of Alto. Sampled by Dr. R. A. Penrose, Jr. T. G. S. A. R. 1892, p. 196.

1258. Cherokee County. Sample of brown coal, passing into pitch coal, laminated in structure, near Jacksonville. T. G. S. A. R. 1892, p. 196.

1259. Cherokee County. Sample of brown coal, slightly lignitic. Fracture even, luster dull, compact firm, with traces of decomposed pyrites. Taken by Dr. Penrose at McBee's Schoolhouse. T. G. S. A. R. 1892, p. 196.

1260. Cherokee County. Sample from south of Alto. Analyzed by Dr. Everhardt. T. G. S. A. R. 1892, p. 196.

1261. Fayette County. Sample from Melcher Coal and Clay Co., O'Quinn. Analyzed by S. H. W. B. A. 23.

1262. Fayette County. Sample from 2 miles west of Muldoon. Sent to Lab. of Univ. Bur. Ec. Geol. by J. T. Wright of Temple. Analyzed 1913 by S. H. W. B. A. 906.

1263. Fayette County. Lignite from Old Big Four Mines, Ledbetter. Represents 8-ft. seam, first stratum, 55 ft. down. Analyzed 1911 by S. H. W. B. A. 61.

1264. Fayette County. From Old Big Four Mine, Ledbetter. Represents 7-ft. seam, lower seam, 95 ft. down. Analyzed 1911 by S. H. W. B. A. 62.

1265. Fayette County. Old Big Four Mine, Ledbetter. 4 ft. of lignite 100 ft. from surface. Analyzed 1911 by S. H. W. B. A. 157.

1266. Fayette County. From Daniel Webster, Ledbetter. Taken from car shipped to Consumers' Fuel and Ice Co., Austin. Analyzed 1911 by S. H. W. B. A. 181.

1267. Fayette County. Upper vein in mines of Lower Stratum Mining Co., Ledbetter. Analyzed 1911 by S. H. W. B. A. 237.

1268. Fayette County. Sample of lignite from Lower Stratum Lignite Mining Co. Sent in by T. T. Felder. Analyzed 1911 by S. H. W. B. A. 1141.

1269. Fayette County. Sample from Lower Stratum Mining Co. Analyzed for moisture only. Analyzed 1911 by S. H. W. B. A. 1226.

1270. Fayette County. Lignite from T. T. Felder, Ledbetter. Lower Stratum Mining Co. Analyzed 1914 by S. H. W. B. A. 1444.

1270a. Fayette County. From H. H. Harrison's land, 3 miles north of Flatonia on S. A. & A. P. Ry. Vein is 22 ft. deep and 8 ft. thick. Sample taken 10 inches from the top of vein. Analyzed 1918 by J. E. S. No. C613.

1270b. Fayette County. Outcrop of vein described under 1270a. Analyzed 1918 by J. E. S. No. C614.

1271. Freestone County. Sample from Col. Wm. Gaines of Austin, marked "J. Garmon, Teague, Texas, Shaft No. 2, from near Donie, Texas." Analyzed 1914 by J. E. S. B. A. 1498.

1272. Freestone County. Sample from Col. Wm. Gaines of Austin, marked "J. J. Garmon, Teague, Texas. Hole No. 4, from near Donie, Freestone County."

1273. Freestone County. Sample of lignite from near Donie, sent in by J. M. Bray. Analyzed 1914 by J. E. S. B. A. 1566.

1274. Freestone County. Sample labeled "No. 1, from shaft on lease of J. M. Bray, Donie." 3 ft. of lower seam, beginning at 2½ ft. from bottom of seam and extending 5½ ft. Sampled by E. L. P. Analyzed 1914 by J. E. S. B. A. 1675.

1275. Freestone County. From shaft on lease of J. M. Bray, Donie. Represents 2½ ft. of lower seam, beginning 5½ ft. and extending to 8 ft. Sampled by E. L. P. Analyzed 1914 by J. E. S. B. A. 1676.

1276. Freestone County. Lignite from shaft on lease of J. M. Bray, Donie. Represents 3½ ft., beginning with 8 ft. and extending to 11½ ft. Sampled by E. L. P. Analyzed 1914 by J. E. S. B. A. 1677.

1277. Freestone County. Sample taken by E. L. Porch on outcrop in creek about 1 mile northeast of Bray's shaft, Donie. Represents 3 ft. 2 in. from top down. Analyzed 1914 by J. E. S. B.A. 1678.

1278. Henderson County. Lignite from the Dallas Lignite Co.'s mine at Fredlow, 1¼ miles east of Malakoff. Analyzed by Ledoux & Co., of New York. U. T. B. 307, p. 99.

1279. Henderson County. Sample taken from same locality as No. 1278 but analyzed by Babcock and Wilcox Co., of New York City. U. T. B. 307, p. 99.

1280. Henderson County. Sample from 6-ft. vein, 8 miles west of Athens. Submitted by the McKay Lignite Mining Co., of Dallas. Analyzed 1914 by J. E. S. B. A. 1596.

1281. Henderson County. Sampled near outcropping 4 ft. thick. One-half mile from test hole for No. 1280. Sent in by McKay Lignite Mining Co., of Dallas. Analyzed 1914 by J. E. S. B. A. 1597.

1282. Henderson County. Sample from 12-ft. vein on 2300-acre tract north of Malakoff, and about 2½ miles from Stockard. Sent in by W. Reid, Dallas, Texas. Anal. 1912 by S. H. W. B. A. 216.

1282a. Henderson County. Sample sent from Malakoff by W. C. Dodd. Analyzed 1916 by J. E. S. No. C102.

1283. Hopkins County. Lignite from Como Coal Co., Como. T. M. S. A. No. 1549.

1284.
1284.
1285. Hopkins County. Samples from deposits 10–12 miles from Sulphur Springs from shaft of W. H. King. No. 1285 analyzed by Dr. Everhardt of the Univ. of Tex. T. G. S. A. R. 1892, p. 161.

1286. Hopkins County. Sample sent in by Crystal Ice Co., Sulphur Springs. Analyzed 1915 by J. E. S. B. A. 2384.

1287.
1288. Hopkins County. Both samples from Como Coal Co., Como, Texas. Analyzed 1911 by S. H. W. B. A. 41 and 75, respectively.

1289. Hopkins County. From test hole on Fry Land, near Como. Thickness 7 to 8 ft. with 1½ in. seam of dirt 1½ ft. from the bottom. Sample submitted by McKay Lignite Mining Co., Dallas. Analyzed by J. E. S. B. A. 1209.

1290. Houston County. Sample of lignite from Houston County Coal Co., near Lovelady. T. M. S. A. No. 1545.

1291. Houston County. Sample from Mr. Crow of the Houston Coal and Mfg. Co., Crockett, Texas. Analyzed 1913 by S. H. W. B. A. 662.

1292. Houston County. Sample taken from supply of lignite furnished The University of Texas power house by Houston Coal and Mfg. Co., Crockett. Analyzed 1914 by J. E. S. B. A. 2129.

1293. Houston County. Sample from Wooters Station, 11 miles south of Crockett. Room 17, north entry. U. T. B. 307, p. 105.

1294. Houston County. Same mine as No. 1293, main entry, 600 feet from shaft, 5.66 ft. cut. U. T. B. 307, p. 105.

1295. Houston County. Same sample as No. 1293 screened through ½ in. bar screen.

1296. Karnes County. Sample from depth of 1011–1013 ft. below surface of well of Manhattan Oil Co., Karnes City. Analyzed by S. H. W. B. A. 851.

1297. Lee County. From Hicks. U. T. B. 365, p. 164.

1298. Lee County. From Blue Ranch. U. T. B. 365, p. 164.

1299. Lee County. From Giddings. Analyzed 1914 by S. H. W. B. A. 1445.

1300. Leon County. From Bear Grass Coal Co., Jewett. H. B. Crosby, Supt. Analyzed 1912 by S. H. W. B. A. 234.

1301.
1302.
1303. Leon County. From Bear Grass Coal Co., Jewett. Analyzed 1912 by S. H. W. B. A. 235, 236, and 256, respectively.

1304. Leon County. Representing a shipment of 1 T. by the Bear Grass Coal Co., Jewett, to E. J. Babcock, Mining Sub-Station, Hebron, North Dakota. Analyzed 1912 by S. H. W. B. A. 307.

1305. Leon County. From mines of Houston Coal and Mfg. Co., Evansville, representing material sent to Hebron, North Dakota, for briquetting. Analyzed by S. H. W. B. A. 342.

1306. Leon County. From mines of Bear Grass Coal Co., Jewett, used for briquetting tests. Analyzed 1912 by S. H. W. B. A. 373.

1307. Leon County. From Bear Grass Coal Co., Jewett. Analyzed 1913 by J. E. S. B. A. 551.

1308.
1309.
1310. Leon County. Three samples from Bear Grass Coal Co. mine at Newby. Samples taken at top of vein, middle, and bottom, respectively. Analyzed 1915 by J. E. S. B. A. 2337, 2338, 2339, respectively.

1311.
1312. Leon County. Samples of dry lignite from Houston Coal and Mfg. Co., Evansville. Analyzed 1913 by S. H. W. B. A. 927 and 928, respectively.

1313. Leon County. Sample of lignite from Newby, screened: opening between bars 1 in., straight ⅝ in. across top and ⅜ in. across bottom. Screenings about 20 per cent of material thrown on screen. Analyzed 1913 by S. H. W. B. A. 933.

1314. Leon County. From F. V. Crosby, superintendent Bear Grass Coal Co., Jewett. Analyzed 1914 by J. E. S. B. A. 1888.

1315. Leon County. Evansville lignite furnished The University of Texas power house. Analyzed 1914 by J. E. S. B. A. 1987.

1316. Leon County. From Bear Grass Coal Mine, Newby. Analyzed 1914 by J. E. S. B. A. 2111.

1317.
1318.
1319. Leon County. Three samples from Houston Coal and Mfg. Co., Evansville, furnished the U. of T. power house on dates Dec., 1914, Feb., 1915, and Mar., 1915, respectively. Analyzed by J. E. S. B. A. 2203, 2299, 2363, respectively.

1319a. Leon County. Sample sent by Bear Grass Coal Co., Jewett. Analyzed 1917 by J. E. S. No. C455.

1320. Limestone County. Sample from near Teague, sent in by H. L. Kniffin. Analyzed 1914 by E. L. P., Jr. B. A. 1669.

1321. Limestone County. Sample from Head's Prairie in southeastern part of county. Analyzed by Prof. Maurie of Chicago. T. G. S. A. R. 1892, p. 173.

1322. Medina County. Sample from Carr Mine, near Lytle, Texas. U. T. B. 307, p. 87.

1323. Medina County. Sample from Bertetti Mine, Lytle, Texas. U. T. B. 307, p. 87.

1324. Medina County. Sample from Carr Mine, Lytle, Mine No. 3, 350 ft. northeast entry No. 6, 51½ in. cut. U. T. B. 307, p. 105.

1325. Medina County. Same mine as No. 1324, but 600 ft. northwest room at middle of northeast entry No. 5, 49¾ in. cut. U. T. B. 307, p. 105.

1326. Medina County. Carr Mine, near Lytle. U. T. B. 365, p. 180.

1327. Medina County. Bertetti Mine, near Lytle. U. T. B. 365, p. 180.

1328. Milam County. From Burnet Fuel Co., Milano. Depth 4 ft. 9 in. Received from Otto Stolle, Austin, Texas. Analyzed by S. H. W. B. A. 46.

1329. Milam County. From mine of American Briquetting Co., Big Lump, Texas. Sampled by E. L. P., Jr., in boiler room of plant. Analyzed 1913 by S. H. W. B. A. 883.

1330. Milam County. From Worley Mine, Rockdale. Analyzed 1901 by O. H. P. and S. H. W. T. M. S. A. No. 1538.

1331. Milam County. From Black Diamond Coal Co., Rockdale. Analyzed 1901 by O. H. P. T. M. S. A. No. 1539.

1332. Milam County. From Lignite Eggette Coal Co., Rockdale. Analyzed 1902 by O. H. P. T. M. S. A. No. 1540.

1333. Milam County. From J. J. Olsen & Sons, Rockdale. Analyzed 1902 by O. H. P. T. M. S. A. No. 1541.

1334. Milam County. From Big Lump Coal Co., Rockdale. Analyzed 1902 by O. H. P. and S. H. W. T. M. S. A. No. 1542.

1335. Milam County. From Aransas Pass Lignite Co., Rockdale. Analyzed 1902 by O. H. P. and S. H. W. T. M. S. A. No. 1543.

1336. Milam County. Sample from deep vein at Rockdale, in mine of the American Lignite Briquette Co. Analyzed 1913 by S. H. W. B. A. 420.

1337. Milam County. Sample from Texas Coal Co., Rockdale. Air-slaked. Analyzed 1913 by S. H. W. B. A. 661.

1338. Milam County. Sample from Texas Coal Co., Rockdale, as taken from bins before being air-slaked. Analyzed 1913 by S. H. W. B. A. 745.

1339. Milam County. Sample from Texas Coal Co., Rockdale. Thoroughly subjected to the action of sun and rain for 26 days. Analyzed 1913 by S. H. W. B. A. 746.

1340. Milam County. Sample from Rowlett and Wells, Rockdale. B. A. 25.

1341. Milam County. Sample from Rockdale Lignite Co., Rockdale. B. A. 28.

1342. Milam County. Sample from Vogel Coal and Mfg. Co., Rockdale. B. A. 29.

1343. Milam County. Sample received from Texas Coal Co., Rockdale. B. A. 39.

1344. Milam County. Sample from Rockdale Coal Mine Co., Rockdale. B. A. 55.

1345. Milam County. Sample from Olsen Mine, Rockdale, 400 ft. east of shaft, 77 in. cut. U. T. B. 307, p. 106.

1346. Milam County. Same locality as No. 1345, except that it was taken 500 ft. east of shaft, 79 in. cut. U. T. B. 307, p. 106.

1347. Milam County. Same as No. 1345. Sample over ¾ in. screen.

1347a. Milam County. From undeveloped mine, 9 miles southeast of Rockdale. Sent by W. A. Butler, Hillsboro. Analyzed 1918 by J. E. S. No. C714.

1348. Morris County. Brown coal, on the Jonathan N. Bohonan headright, about 5½ miles south of Daingerfield. From vein at S. H. Pruitt's house, 15 in. thick. T. G. S. A. R. 1892, p. 160.

1349. Palo Pinto County. Sample from near Gordon. T. A. S. III. p. 25.

1349a. Panola County. From a farm of Dell R. Todd, near Gary. Vein is 2 ft. deep and 3 ft. thick. Analyzed 1917 by J. E. S. No. C520.

1350. Robertson County. From Central Texas Mining, Mfg. and Land Co., Calvert Bluff. T. M. S. A. No. 1544.

1351. Robertson County. Calvert Mine at Calvert, Room 4 of north entry 1, south, 250 feet south of opening, upper 81¼ in. bed, 77 in. cut. U. T. B. 307, p. 106.

1352. Robertson County. Sample from Calvert Mine, at Calvert, Room 8, off east entry north, 550 ft. northeast of opening, 83½ in. bed, 78¼ in. cut. U. T. B. 307, p. 106.

1353. Robertson County. From near Bremond. Sample sent in by D. B. Matthews. Analyzed 1913 by S. H. W. B. A. 823.

1354. Robertson County. On farm of Strumensky & Son, 2½ miles northeast of Wootan, seam 6½ ft. in well 70 ft. deep. Analyzed 1913 by S. H. W. B. A. 953.

1355. Robertson County. 1¼ miles southwest of farm of Strumensky & Son, near Wootan. Thickness of seam 6½ ft. in well 73 ft. deep. Analyzed 1913 by S. H. W. B. A. 954.

1356. Robertson County. One-half mile north-northwest of Strumensky & Son's farm, from 6 ft. seam in well 53 ft. deep. Analyzed 1913 by S. H. W. B. A. 955.

1357. Robertson County. One-fourth mile from Strumensky & Son's farm, near Wootan. Thickness of seam 3½ ft. in well 33½ ft. deep. Analyzed 1913 by S. H. W. B. A. 956.

1358. Robertson County. New Mine. Sample taken from 700 ft. from shaft north, depth of 60–70 ft. The Southwestern Fuel Co., Calvert. Thickness of seam 6½ ft., first seam. Analyzed 1913 by S. H. W. B. A. 957.

1359. Robertson County. From Southwestern Fuel Co., Calvert. Received from C. M. Beard, Austin, Texas. Analyzed 1913 by S. H. W. B. A. 974.

1360–1374. Robertson County. Lignite from Southwestern Fuel Co., Calvert. Sampled by W. B. Phillips from I. & G. N. car No. 1534 at the U. of T. power house. This lignite was screened through mesh screens of various sizes as given below and used in tests on the Belvet Rocking Grates. Analyzed 1914 by J. E. S. as follows:

1360. Screened through 1 in., 8%. B. A. 1750.
1361. Screened through 1 in. and on ½ in., 32%. B. A. 1751.
1362. Screened through ½ in. and on ¼ in., 20%. B. A. 1752.
1363. Screened through ¼ in. and on ⅛ in., 20%. B. A. 1753.
1364. Screened through ⅛ in., 20%. B. A. 1754.
1365. Screened through 1 in., 10%. B. A. 1755.
1366. Screened through 1 in. and on ½ in., 34%. B. A. 1756.
1367. Screened through ½ in. and on ¼ in., 20%. B. A. 1757.
1368. Screened through ¼ in. and on ⅛ in., 20%. B. A. 1758.
1369. Screened through ⅛ in., 16%. B. A. 1759.
1370. Screened through 1 in., 12%. B. A. 1760.

1371. Screened through 1 in. and on ½ in., 26%. B. A. 1761.
1372. Screened through ½ in. and on ¼ in., 24%. B. A. 1762.
1373. Screened through ¼ in. and on ⅛ in., 18%. B. A. 1763.
1374. Screened through ⅛ in., 20%. B. A. 1764.

1375. Rusk County. Sample from 5 miles southeast of Henderson, 2½ miles from railroad. Two seams 38 in. thick. Analyzed 1915 by J. E. S. B. A. 2632.

1376. Rusk County. Sample from Graham's Lake, 12 miles west of Henderson, 3-6 ft. thick. U. T. B. 365, p. 209.

1377. Rusk County. Sample from near Iron Mountain. Analyzed by Dr. Riddell. T. G. S. A. R. 1892, p. 194.

1378. Shelby County. Sample from Timpson. T. M. S. A. No. 1546.

1379. Smith County. Sample of lignite from depth of 800-900 ft. near Whitehouse. Analyzed 1912 by N. C. Hamner of Dallas. Analysis obtained from T. M. Coupland of Troupe. U. T. B. 307, p. 102.

1380. Smith County. Sample from Alec and Albert Woldert, Tyler, obtained from outcropping near Spring. Analyzed 1910 by S. H. W. B. A. 34.

1381. Smith County. Sample obtained on eastern edge of spring branch at seam by Dr. Albert Woldert of Tyler. Analyzed 1911 by S. H. W. B. A. 35.

1382. Somervell County. Sample of lignite obtained at Hill Creek, about ½ mile from north of Bosque County and about ½ mile southwest of Brazos River, near crossing of Hill Creek by the lower Glen Rose and Morgan Road. Sent in by Miss Lucy Tuggle, Kopperl. Black lustrous color and breaks with conchoidal fracture. Analyzed 1915 by J. E. S. B. A. 2367.

1383. Titus County. From Cookville Coal and Lumber Co., Mount Pleasant. Analyzed 1910 by S. H. W. B. A. 18.

1384. Titus County. Sample of lignite from Libby Coal Co., Cookville. Sent in by the Texas Public Service Co. of Mount Pleasant. Taken from 8-ft. seam, 50 ft. below surface; represents entire seam. Analyzed by J. E. S. B. A. 1725.

1385. Upshur County. Sample from R. B. Nelson, Gilmer. Analyzed by S. H. W. B. A. 54.

1386. Upshur County. Sample from R. E. Ezekiel, Kelsey, taken from top of vein. Analyzed 1911 by S. H. W. B. A. 148.

1387. Upshur County. Sample from R. E. Ezekiel, Kelsey, taken from bottom of vein. Analyzed 1911 by S. H. W. B. A. 149.

1388. Van Zandt County. Sample from Edgewood Coal and Fuel Co., Wills Point. Analyzed by S. H. W. B. A. 36.

1389. Walker County. Sample from 10-15 miles north of Huntsville and south of Trinity River. Analyzed 1909 by P. S. T. Sample obtained from G. A. Wynne of Huntsville. U. T. B. 307, p. 103.

1390. Washington County. Lignite from Mrs. Heber Stone, Brenham. Analyzed 1914 by J. E. S. B. A. 2101.

1391. Wilson County. Sample from 3-ft. seam in Cibolo Creek. Sent in by Miss Angela Hendricks, Sutherland Springs. Analyzed by J. E. S. B. A. 2574.

1392.
1393. Wood County. Two lignite samples from North Texas Coal Co. of Alba. T. M. S. A. Nos. 1547 and 1548, respectively.

1394. Wood County. Sample of lignite from Consumers' Lignite Co., Hoyt. Analyzed 1909 by Crossley Bros., Manchester, England. U. T. B. 307, p. 104.

1395. Wood County. Sample from eastern part of the county. Sent in by B. Snyder of Marshall. Analyzed by J. E. S. B. A. 2272.

1396. Wood County. Lignite from Alba. Received from Consumers' Lignite Co., Dallas. B. A. 17.

1397. Wood County. Sample from Alba. Received from Lone Star Lignite Co., Dallas. B. A. 22.

1398. Wood County. Sample from Alba. Received from Alba-Malakoff Lignite Co., Dallas, labeled "Alba-Malakoff." B. A. 59.

1399. Wood County. Lump lignite from Consumers' Lignite Co., Alba. Analyzed by S. H. W. B. A. 913.

1400. Wood County. Nut lignite from Consumers' Lignite Co., Alba. Analyzed by S. H. W. B. A. 914.

1401. Wood County. Dust lignite from Consumers' Lignite Co., Alba. Analyzed by S. H. W. B. A. 915.

1402. Wood County. Dust lignite, dry. From Consumers' Lignite Co., Alba. Analyzed by S. H. W. B. A. 916.

1403. Wood County. From Hoyt No. 1 Mine, south entry, 2500 ft. from mouth, 8¼ ft. cut. U. T. B. 307, p. 107.

1404. Wood County. Same as No. 1403. Foot of air shaft, 94 in. cut.

1405. Same as No. 1403. Run of mine.

1406. Wood County. Same as No. 1403. Screened.

1407. Wood County. Same as No. 1403. 1100 ft. southeast of slope, 6½ ft. cut.

1408. Wood County. Same as No. 1403. 400 ft. northeast of slope, 8 1/6 ft. cut.

1409. Wood County. Same as No. 1403. Run of mine.

1410. Wood County. Screened lump lignite from Consumers' Lignite Co., Hoyt. Sampled by W. B. Phillips at boiler plant of Lone Star Ice Co. Passed over 1 in. screen. Analyzed 1914 by S. H. W. B. A. 1716.

1411. Wood County. Lump lignite, screened through 1 in. and on ½ in., excluding large lumps, 21.4%. Sample from Consumers' Lignite Co., Hoyt. Sampled by W. B. P. Analyzed 1914 by S. H. W. B. A. 1717.

1412. Wood County. Screened lump from Consumers' Lignite Co., Hoyt. Screened through ½ in. and ¼ in., excluding all large lumps. 11%. B. A. 1718.

1413. Wood County. Lump lignite from Consumer's Lignite Co., Hoyt. Screened through ¼ in. and on ⅛ in., excluding all large lumps, 20.90%. Sampled by W. B. Phillips. B. A. 1719.

1414. Wood County. Screened lump lignite from Consumers' Lignite Co., Hoyt. Sampled by W. B. P. at the boiler plant of the Lone Star Ice Co. of Austin. Screened through ½ in., excluding all large lumps, 11%. B. A. 1720.

1415–1419. Wood County. From Consumers' Lignite Co., Hoyt. Sampled by W. B. P. at the U. of T. power house from top of car No. 23510. Screened through various size screens to determine the variation of percentage of the constituents with size of particles. All analyses reported as "received." Analyzed 1914 by J. E. S.

- 1415. Screened and sample taken on 1 in. screen, 14%. B. A. 1728.
- 1416. Screened through 1 in. and on ½ in., 20%. B. A. 1729.
- 1417. Screened through ½ in. and on ¼ in., 24%. B. A. 1730.
- 1418. Screened through ¼ in. and on ⅛ in., 21%. B. A. 1731.
- 1419. Screened through ⅛ in., 21%. B. A. 1732.

1420–1430. Wood County. Screened nut lignite from Consumers' Lignite Co., Hoyt. Sampled by J. E. S. Middle part of car No. 23510. Analyzed 1914 by J. E. S. All analyses are B. A.

- 1420. Screened on 1 in., 22%. B. A. 1733.
- 1421. Screened through 1 in. and on ½ in., 32%. B. A. 1734
- 1422. Screened through ½ in. and on ¼ in., 10%. B. A. 1735.
- 1423. Screened through ¼ in. and on ⅛ in., 14%. B. A. 1736.
- 1424. Screened through ⅛ in., 22%. B. A. 1737.
- 1425. All sizes of lumps. B. A. 1738.
- 1426. Screened on 1 in., 20%. B. A. 1739.
- 1427. Screened through 1 in. and on ½ in., 38%. B. A. 1740.
- 1428. Screened through ½ in. and on ¼ in., 20%. B. A. 1741.
- 1429. Screened through ¼ in. and on ⅛ in., 16%. B. A. 1742.
- 1430. Screened through ⅛ in., 6%. B. A. 1743.

1431–1435. Wood County. Screened nut lignite from Consumers' Lignite Co., Hoyt. Sampled by J. E. S., bottom part of car No. 23510. Analyzed 1914 by J. E. S. All analyses are B. A.

- 1431. Screened on 1 in., 32%. B. A. 1744.
- 1432. Screened through 1 in. and on ½ in., 40%. B. A. 1745.
- 1433. Screened through ½ in. and on ¼ in., 16%. B. A. 1746.
- 1434. Screened through ¼ in. and on ⅛ in., 8%. B. A. 1747.
- 1435. Screened through ⅛ in., 4%. B. A. 1748.

1436. Zavala County. From a drill hole of an artesian well 12 miles west of La Pryor, at a depth of 118 ft. Received from W. J. Armstrong. Analyzed 1913 by S. H. W. B. A. 926.

1437–1458. Ultimate analyses of lignites from various counties in the State. This table copied from Dumble: "Brown Coal and Lignite of Texas," T. G. S. A. R. 1892, p. 213. Also U. T. B. 307, p. 110.

1459–1462. Ash from Wood County Lignite. Sample of lignite from Consumers' Lignite Co., Alba. Each marked "D. McNn. P." B. A. 617, 618, 619, and 620, respectively.

No Pennsylvanian, Cretaceous, or cannel coal is being produced at present in Texas. The production of lignite reported for the year 1933 was 821,878 tons valued at $833,000.

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WATER SUPPLIES

Water is the most essential and therefore the most important natural resource. Without it all life would be impossible. It is the medium through which most rocks and mineral deposits form. It is, contrariwise, the main medium for the agencies and processes which alter and destroy rocks and minerals. This remarkable substance determines, within the relatively narrow range of temperature at which it is liquid, the equal restricted limits of organic existence.

Upon solidifying (freezing) it becomes the purest of rocks and, aggregated in large masses as a rock anywhere except on the flattest of surfaces, it becomes plastic by the influence of gravity and flows, thereupon becoming an active agent of glacial erosion. In liquid form, on the land surface and in shallow depths in lakes and seas and likewise in underground channels in otherwise solid rocks, wherever it carries sediment in the form of pebbles, boulders, or sand and is actively circulating, either under the influence of gravity or by means of waves and currents, it erodes the rocks and carves out by the processes of sculpture the landscapes of the earth. At relatively low temperature it changes into a gas capable of penetrating minute spaces, carrying often active chemical reagents which alter and destroy rocks and minerals and form new mineral deposits. Suspended in the atmosphere, the vapor of water functions as an efficient blanket which prevents the rapid dissipation of the heat into outer space. The processes of utilization of most natural resources require the use of water.

Classified with respect to source, there are three kinds of underground water: (a) that derived from rainfall or snowfall, known as meteoric or vadose; (b) that derived from igneous or molten rocks, known as magmatic or juvenile; and (c) that retained in sedimentary rocks when they are deposited, known as connate. Underground water may further be sudivided into that present in pore spaces, fracture spaces, or other interstices in the rocks; that occurring in underground channels formed either by solution or by fracturing of rocks; and that retained by the rocks, when formed and in chemical combination with them and in their constituent minerals. The water absorbed by rocks and minerals can be driven off as vapor (gas) when they are heated to the boiling point of water (212° Fahrenheit or 100° Centigrade). That in chemical combination is classed either as water of crystallization, which is driven off readily at fairly low temperature, or water of constitution, which is removable only at a higher temperature. The water combined in original or primary igneous rocks averages about 1½ per cent of the total mass. This is additional to the magmatic or juvenile water originally present in the molten silicate solution which formed the igneous magma and which is liberated upon the magma congealing ("freezing") and becoming a solid. Part of this magmatic water escapes from the magma both as a gas and as a hot or warm liquid, where allowed to do so upon relief of pressure, brought about either by the magma rising into higher levels or by its contraction into lesser volumes upon cooling. All those sedimentary rocks deposited under water are originally saturated with it, it being present in interstices or pores between the solid particles of sand, limestone, clays, marls, and gravels. Some of this interstitial water may be forced out subsequently by pressure, but some of it remains in openings between the particles even in the finest grained and densest clays, shales, slates, or schists. Clay itself, unless composed entirely of very fine particles of quartz, is a hydrated mineral, containing water in chemical combination. Clays are impervious because the interstices between the grains are already filled with water, tightly adhering by surface tension (adsorption) to their constituent particles.

The connate water in marine sediments may have the original chemical composition of the water of the sea or ocean in which they were deposited, or the connate water may now be diagenetic, that is, changed from its original composition through subsequent chemical processes. Thus many oil field waters are diagenetic, being greatly different in chemical composition and containing a higher percentage of mineral matter than the original connate water. Many deeper well waters, and waters of shallower wells also, are either originally connate or else subsequently changed in chemical composition to diagenetic. Thus, even the water from a shallow well which derives its supply from a limestone is apt to be "hard" because of its content of calcium bicarbonate derived from solution of the limestone, and wells in gypsum or rock salt are high in calcium sulphate and rock salt derived from these readily soluble materials. The "softest" well waters derive their supplies from the relatively insoluble rhyolitic volcanic rocks, granite or pure quartz sandstones, sands, gravels, or conglomerates. However, if the waters in quartzose sediments derive part or most of their supply from other sources or these waters have passed through rocks containing soluble minerals they may be highly mineralized.

CLIMATIC FACTOR IN TEXAS UNDERGROUND WATER

Most of the Texas underground water supply is derived from that portion of the surface precipitation (rainfall and snowfall) which seeps into or is absorbed by the surface soils and porous bed rocks.

The more porous soils and rocks are sandy, gravelly, or bouldery in nature. Most hard and dense outcropping rocks contain open fractured spaces (faults and joints) which rain water enters. All sedimentary rocks contain open bedding planes which collect water, and the volcanic rocks, besides their fracture planes, contain more or less open places between the different volcanic flows, and their pyroclastic rocks (volcanic glass, ash, tuff, and breccia) are highly porous except where they subsequently have been tightly cemented. Clays and shales absorb the least amount of the precipitation. Therefore, the underground water supply depends very largely upon the climate and especially upon such climatic factors as rainfall and snowfall, temperature and wind. Precipitation supplies the water while high temperature and wind decrease the supply through their evaporating effects.

Much of the rainfall on the High Plains and Trans-Pecos Texas is summer rainfall derived from the Pacific Ocean. The rest of the state gets its rainfall from the Gulf of Mexico. It is well known that the rainfall on the lower plains constituting most of Texas decreases with the distance from the Gulf, it being relatively heavy in the eastern and southeastern part and relatively sparse in the western interior. The rate of decrease towards the interior is, on the whole, rather uniform and gradual but depends somewhat upon the surface elevation, higher areas, being cooler, causing the precipitation of more moisture. Therefore, the Edwards Plateau receives slightly more rainfall than the adjoining lowlands.

The problem of water supply in Texas becomes acute west of the 98th Meridian, although in south Texas, to the south of San Antonio, the line shifts eastwards to the 97th Meridian. To the west of this somewhat indefinite line, irrigation becomes necessary in order to insure regularly profitable crop yields. To the east of the line, irrigation during hotter and drier times will improve greatly agricultural yields. Even in the wettest part of the state, the southeast, where the average annual rainfall is from 40 to 50 inches, there is extensive irrigation for the production of rice.

The rainfall in Texas is characterized by fairly extreme fluctuations in amount from year to year; therefore, the annual average is quite misleading. The following table from U. S. Weather Bureau data to the end of 1930 shows these extremes for a few places; they are characteristic of all places in Texas.

Place	Annual Average *Inches*	Maximum *Inches*	Minimum *Inches*
Beaumont	49.35	95.28	20.83
Houston	46.00	73.1	17.6
San Antonio	27.3	50.4	10.3
Brownsville	27.2	60.3	12.1
Del Rio	18.6	37.75	7.65
Fort Davis	16.66	27.68	6.78
El Paso	8.7	21.9	2.3
Abilene	24.5	41.5	10.9
Dallas	37.2	59.6	18.7
Clarksville, Red River County	48.24	109.38	25.39
Amarillo	21.5	39.6	11.2

Dryness of the air, heat of the sun, and wind cause evaporation of moisture. All three are particularly effective in the western part of Texas where rainfall likewise is less. West of the 100th Meridian the average amount of evaporation is about 4 times the average rainfall, and in Trans-Pecos Texas it exceeds that figure. The mean annual relative humidity is greatest in the pine timber belt of east Texas and in the Gulf prairie along the Gulf of Mexico. The relative humidity is the percentage of moisture which the air contains at a given temperature of the total amount which it would contain at that temperature if it were saturated. Mean annual relative humidity of some places in Texas is as follows:

Galveston	77.7
Corpus Christi	77.0
Brownsville	74.7
Palestine	68.3
Austin	65.7
San Antonio	63.0
Fort Worth	62.0
Del Rio	59.3
Amarillo	57.3
Abilene	55.7
El Paso	37.7

Total annual free evaporation from open pans has been determined to be as follows:

Place	No. of Years	Average Temperature *Degrees*	Amount of Evaporation *Inches*
Beeville	9	70.6	59.965
Austin	10	67.4	64.092
Spur, Dickens County	7	61.4	63.944
Balmorhea, Reeves County	1	64.1	62.079
Dilley, Frio County	1	70.8	87.859

At Amarillo the eight-year average total open pan evaporation for the six months growing season (April 1 to October 1) is 53.26 inches, and at Big Spring, Howard County, a seven-year average for the same six months is 60 inches. The average temperature of Amarillo is 56.5° and of Big Spring is 64.0°.

Evaporation generally increases gradually from the eastern to the western part of the state. Total annual evaporation from a free water-surface ranges from 45 to 55 inches in the eastern part of the state, from 55 to 65 inches in the central part, and from 65 to 75 inches in the western part, or a range of four to six feet per annum. Rainfall, on the other hand, varies in exactly the opposite direction, ranging from 52.81 inches at Beaumont, in the Gulf Coast region, to 13.75 inches at Balmorhea, in the Trans-Pecos region. The temperature, atmospheric humidity, wind movement, and rainfall all have a close relationship to evaporation, and, together with the altitude and geographical location, largely determine the extent of losses through evaporation which may be expected in any given region of the state.[1]

As an example of the influence of temperature upon evaporation, it may be noted that the famous wheat belt of Minnesota and North Dakota has no greater rainfall than the Llano Estacado but with its cool temperature has only half the evaporation of the latter.

The data of the hourly wind velocities in miles per hour for the following places are:

Brownsville	9.8
Del Rio	10.0
El Paso	10.4
Abilene	10.0
Amarillo	12.5
Dallas	9.6
Fort Worth	10.2
Austin	8.7
Corpus Christi	11.7
Galveston	10.6
Groesbeck	10.1
Houston	9.2
Palestine	7.9
Port Arthur	8.9
San Antonio	8.2

The strong winds of the coast are coupled with high humidity, which keeps the evaporation low, but the strong winds of western Texas, combined with low atmospheric humidity, cause excessive evaporation.

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[1]From abstract, published in Circular 71, December, 1933, of "Rate of water evaporated in Texas," by R. E. Karper, Texas Agricultural Experiment Station, Bull. 484, 1933.

Although underground waters are treated almost exclusively in this work, it is well to note that geology is concerned also with the utilization of the waters on the surface of the earth, either for irrigation or for power, for human or for industrial consumption, and likewise in inhibiting or preventing, so far as may be possible, damage which may be done by uncontrolled water. The geologist must determine the feasibility of dam and reservoir sites, determine the availability and suitability of materials for the construction of dams and ditches, and by using sound phyiographic principles avoid the location of reservoirs in places where they will become rapidly filled with sediment.

The principal problem in Texas is that of making the greatest possible utilization of water supply on the one hand and, on the other, prevention of flood damage in and the draining and reclamation of the extensive areas of rich valley and other coastal and swampy lowlands. The magnitude of the problem is scarcely realizable. The most fertile lands of the state and of the nation are in the river valleys which must ultimately be reclaimed and saved from the danger of floods. Floods are a danger in most of the valleys of Texas. In east Texas large areas of lowlands await reclamation, and in west Texas there is a large acreage of land which can be made productive so far as water for irrigation can be made available. The task will not be finished until every acre of utilizable agricultural land has been made to fulfill to the utmost human need.

In the state of California there has been proposed a plan, which experts consider to be entirely possible, to utilize all the water derived from rain or snowfall of both flood and normal stages of stream flow, which is supplied to the drainage basin of the great Central Valley of the state. This plan contemplates complete flood control and complete utilization of the water for irrigation, hydroelectric power, and other purposes.

It is beginning to be realized that the whole drainage basin of a stream is a unit and is best utilized by the carrying out of a comprehensive plan for the whole rather than for some part of it. By so doing many costly and avoidable mistakes of the past would not have been made. An example is afforded by one of the main streams of Oregon, the waters of which are needed for power and irrigation but along which two railroad lines were built so low in the valley that they must be rebuilt on higher levels before the river can be utilized. Highways are often built where reservoirs are later established and roads and railways constructed in valleys and lowlands where they are damaged by floods and where transportation facilities cease during flood stages. For the last great Mississippi Valley flood some of the railroads in southern Louisiana were forced to cease operations, and a number of costly bridges were lost, and the only railroad which succeeded in operating trains, which had been constructed originally on the highest possible land, was forced to elevate its tracks during the high water period. The destruction brought about by floods has far too often been increased by failure to build bridges and culverts large enough to permit the rapid drainage of flood waters, which have backed up against these artificial obstructions until they have broken through with a force more destructive than would have been possible otherwise. Within the last twenty years destructive floods in three of the larger cities of Texas have been caused by this interference with Nature's laws. Dams on two Texas rivers have been built in creviced limestone through which there has been much loss of reservoir water by seepage.

A comprehensive plan for full control and utilization of a drainage basin is now being carried out in the Tennessee River Project and such plans have been prepared for the Columbia River, the great Colorado River of the west, and for some other western rivers.

Texas rainfall statistics for the last half century show that the annual extremes vary for the maximum as compared with the minimum all the way from 3 to 10 times. Therefore, it is apparent that no stream in the state is free from the possibility of dangerous floods from rainfall alone. In the original state of nature, streams attain a balance between the processes of erosion and deposition along their courses. This amounts to an adjustment of gradients, particularly in streams of low gradients in plains areas. Man in Texas has overthrown this balance in at least four important respects: (1) by denuding areas of timber; (2) by putting into cultivation tracts formerly forested or covered with grass sod or herbaceous or scrubby vegetation; (3) by excessive overgrazing of grasslands; and (4) by artificially obstructing stream courses. The first three have increased the rate of run-off and at the same time have increased the load of sediment and débris derived from the areas denuded of vegetation. Much soil has been removed from large areas put in cultivation and the land has been gullied and rendered worthless. The growth of gullies has likewise been marked in overgrazed areas. The result has been the clogging of stream courses with débris and the raising of the stream beds. This latter process combined with artificial obstructions to run-off explains the distressing general experience that floods are becoming greater.

All the larger rivers of Texas from the Trinity to the Rio Grande, with the Pecos alone excepted, and including Red River farther east, head in areas where rainfall is deficient for agriculture, at least in some years, and flow into areas where reclamation of valley and swampy areas is necessary. Therefore, the problem in the central and northwestern parts of the state is the impounding of stream waters for irrigation, municipal water supply, and hydro-electric development. This, if properly done, will aid greatly flood control and drainage in the lower valleys. However, the experience of France has demonstrated that the proper method of stream control begins in the gullies and very headwaters of streams, in the fields of the farmer and ranchman, preventing soil from washing away and land from being rendered useless by gullying. When all the headwaters, tributaries, and gullies are adequately controlled, the problem for the whole drainage basin is largely solved. Gullying should be prevented for yet another reason, which is that, if unrestrained, it leads to the excessive drainage and drying out of arable soil. In the Gulf Coast country, where land is flat and water-logged, the construction of ditches along roads has in many cases dried out adjoining lands sufficiently to enable them to be cultivated profitably. Many drainage ditches are constructed for the same purpose in the flat coast prairies. Further reclamation of the coast prairie lands may be brought about by tiling, which has been successfully and extensively done in many originally undrained areas in the glacial drift and stream valleys of the north.

The same porous tile is used for exactly the opposite purpose in the irrigation of valuable fruit lands in the west, particularly in California. In this case the fullest utilization and conservation of the water is the aim, and the water is carried underground in order to prevent its loss by evaporation. Such underground irrigation is as old as written historical records. It has been practiced since ancient times, especially in Persia and in the deep depression of

Turfan in central Asia. It has made the orchards and gardens of these two regions famous for many centuries. The underground water tunnels are known as karezes. Water from mountain streams or springs is impounded in either surface or underground reservoirs either at its sources in springs or where mountain streams leave their bed rock gorges and enter piedmont alluvial fans. The subterranean underflow in alluvial deposits is likewise directed into the underground channels. To some extent the same methods are possible in certain areas in Trans-Pecos Texas where their use was advocated by W. H. von Streeruwitz more than forty years ago.

SOME GENERAL DEFINITIONS AND PRINCIPLES CONCERNING UNDERGROUND WATER

All rocks contain water both in combinations and in the free state. Rocks with extremely small openings, such as clay, shale, and some igneous and metamorphic rocks, may retain their free water by the force of capillarity, friction, surface tension, or absorption. This water can be dried out at temperatures up to the boiling point but it will not be yielded up to wells. Most clays and shales are saturated with water, but their pore spaces are so small that water will not pass freely through them and hence they are really impervious and form what are known as "cap rocks" for the retention beneath them of water, gas or oil, confined accordingly in many instances under hydrostatic (water) pressure or head (also termed static head). Water confined under hydrostatic pressure is known as artesian and will rise to some extent when reached in a well drilled through an impervious cap rock into a porous water-bearing stratum underneath. Water under sufficient hydrostatic or artesian head to rise above the surface of the ground in a well is known as flowing artesian water.

A water sand, in common speech, is any rock, formation, or horizon which is porous and contains water which will flow into a well. Many such are real sands or sandstones but others are porous or honeycombed limestones, vesicular volcanic lavas, porous volcanic ash (tuff), breccia or agglomerate, and beds of unconsolidated gravel or conglomerate (cemented gravel). Wells often obtain their water supplies from open fissures produced by jointing or faulting.

Bedding planes between different layers of rock often yield large supplies of water. In limestone or other water-soluble rocks, underground passages or caverns are filled with water beneath the ground water level or table, which latter is the uppermost zone in which openings in the rocks are filled entirely with water.

The hydrostatic or artesian head or pressure amounts to the difference vertically (in altitude or elevation) between the point where the water-bearing formation is penetrated in a well or other artificial or natural (spring) opening and the hydrostatic level of that formation, proper deduction being made for loss of head brought about by friction encountered by the water in its movement between the two points.

For artesian water it is necessary to have (1) a continuous porous bed of rock which has a higher elevation in the region of its outcrop or catchment area than in a region where it is tapped by a well or spring, and (2) an impervious bed or cap rock overlying the porous, saturated, water-bearing bed so as to prevent the upward escape of the water in such quantities as to cause the entire loss of the hydrostatic or artesian head. The structures favorable for artesian water are (1) synclines or downfolds, (2) downfaulted areas or "blocks," and (3) monoclines or homoclines in which the strata dip more or less uniformly in one direction and in which outcropping porous beds in the up-dip direction may or may not pass down the dip by a gradual change in nature of sediments into impervious beds. The best examples in Texas of large synclinal areas are those underlying the High Plains (Llano Estacado and Panhandle) and the Toyah basin of northwestern Texas in which the Permian and Pennsylvanian rocks are downwarped into a large syncline but in which the deeper waters, which will flow out to the surface in wells, are too highly mineralized to be utilizable, and in the northeast Texas syncline in which the Woodbine and Nacatoch waters of the Cretaceous are also highly mineralized but the waters of the Wilcox sands and Carrizo and Queen City sands of Claiborne age of the Eocene yield potable waters, except in the vicinity of salt domes. Important downfaulted blocks occur in the Llano uplift of central Texas and in the Balcones fault zone. Monoclinal sand, sandstone, and limestone artesian horizons occur in the Cretaceous and Cenozoic of the Gulf Coastal Plain, in the Cretaceous of the Edwards

Plateau, and in the westward-dipping monocline of Pennsylvanian rocks in north-central Texas.

In association with igneous eruptions, steam or hot water may rise to the surface in fumaroles, solfataras, hot springs, or geysers. The propelling force in these cases may not be hydrostatic pressure but the expansion of steam; the water or steam can be of either magmatic or meteoric origin. Vast quantities of water vapor are erupted as hot steam in volcanic outbursts and much of this condensing in the air pours down as rain which may be so copious as to produce a deluge and wash vast quantities of volcanic mud and ash down the sides of the volcanoes and produce very destructive floods and volcanic mud flows.

Not all hot springs or hot wells derive their heat from igneous activity. In some cases the heat is produced by underground chemical reactions, and in other cases the water may rise sufficiently rapidly from relatively great depth in a fissure, cavern or well so as not to lose all its original heat. Increase of heat downwards into the earth amounts to about 1° Fahrenheit for every 60 feet, computed from the average annual temperature at the surface, but the rate varies within wide limits. In northeastern Texas the rate of downward increase of heat amounts to 1° Fahrenheit for each 42 to 44 feet, shown, for example, in the hot well at Marlin, which is 3330 feet deep and yields water with a temperature of 147° Fahrenheit—the mean annual surface temperature at Marlin being about 67°. In various localities where rocks of high heat conductivity, such as the more dense rocks of the pre-Cambrian and early Paleozoic or the salt or anhydrite of salt dome intrusions, are brought by upfolding or upfaulting relatively close to the surface, heat is conducted from the earth's interior to the surface at a greater rate and the thermal gradient becomes less than 40 feet to a degree. Spring or well water is apt to be cooler in summer than the temperature of the air at the surface, but very rarely is it cooler than the mean annual temperature, and in winter it is generally warmer than the surface temperature. The deeper the source of the water, the warmer is its temperature.

The water level is higher after a heavy rain than in a prolonged spell of dry weather and at the end of a rainy season than at the end of a dry season or a drought. Flowing wells or springs in which the hydrostatic head is not much above the elevation of the ground fluctuate greatly in flow in wet and dry seasons. They may cease to flow in times of prolonged drought, and after exceptionally heavy rainfall both their rate of flow and the height to which they will flow may increase greatly. For the same reason the water level in pumping wells will fluctuate. If barometric (air) pressure decreases, the rate of flow and the height of water increase. Along sea coasts, water level in wells in porous materials continuous between the wells and the bottom of the sea or ocean will rise and fall with the tides. The same water-bearing horizon may be saturated with salt water under the sea and with fresh water beneath the land and the two not diffuse to any great extent. This is not a common case along the Texas coast because the formation there is impervious clay and tides are small, but it is prevalent in areas where sands or other porous rocks pass from the land out to sea.

All underground water contains some mineral matter, dissolved from the rocks in its passage through them. The purest and "softest" underground waters are either those which have travelled very little distance underground or else those which have travelled through pure silica sands or sandstones or equally insoluble granites or rhyolitic volcanic rocks. Rain water absorbs considerable oxygen and carbon dioxide from the air and in thunderstorms may contain also nitrous or nitric acid. All these are potent chemically, decomposing many rocks and dissolving various mineral substances. Organic decay, especially that of vegetation, generates many substances which are relatively powerful chemical reagents. Combination of these chemicals carried downward by the water from the surface with others in underground rocks, minerals, and water, forms acids and alkalies which dissolve other substances underground. As an instance, sulphides combining with water form sulphurous and sulphuric acids. Waters carrying carbon dioxide rather readily dissolve carbonates, such as limestone. Chlorides, such as rock salt, and sulphates, such as gypsum and anhydrite, are readily soluble in water, especially where underground waters circulate, but there is relatively little solution where underground waters are "stagnant" ("ponded") and circulate with extreme slowness or not at all.

More minerals are taken into solution where the waters are warm or hot than where they are colder. The more removed in distance the underground waters are from their surface source or intake, the more apt they are to be relatively highly mineralized. Thus in the gulfward-dipping monocline of the Gulf Coastal Plain the underground waters are relatively fresh (non-mineral) near the surface outcrops of the water-bearing horizons, but they become progressively more mineralized down the dip towards the Gulf, gathering mineral matter as they travel farther and, perhaps more especially, deriving most of their mineral content from connate brackish and sea water remaining in the strata from the time they were deposited.

The ground water level, or zone below which rocks are saturated with water, is important from the standpoint of shallow non-artesian water supply and determines the hydrostatic head of generally deeper or artesian waters. The ground water level is constantly fluctuating, rising during the rainy season and lowering during times of drought. In hilly country the ground water level is deeper beneath the surface under the hills than in valley areas where the surface is lower but it is higher in absolute altitude beneath the hills. To this rule there are two important exceptions. When the top of the hill is covered with sand or gravel, porous limestone, or volcanic tuff which overlies clay, shale, or other impervious beds outcropping on lower surfaces, and in valleys, as, for example, in certain places in the Gulf Coastal Plain, shallow wells can be had on the hills and not in valley or lower areas. Often, in such places, there are springs or seeps along the hillsides at the contact of the porous beds above with the impervious beds below. The impervious beds check the downward movement of the ground water by percolation, and hence it flows out in lower places at the surface in springs or caves and seepages. In such conditions there is what is known as a "perched water table." Another exception to the general rule occurs in the case of a stream flowing through porous materials in a dry country and contributing to the underground supply by seepage through the bed of the stream. In this case the ground water level is both closer to the surface and higher in absolute elevation underneath and in the vicinity of the stream than underneath the neighboring highlands. For example, such streams as Medina, Sabinal, Frio, and Nueces rivers in Medina and Uvalde counties and Las Moras Creek in Kinney County lose their waters by seepage into the sand and gravel valley deposits in flowing southward from the springs along the Balcones fault zone. Similarly, Pecos River and the Rio Grande and the creeks of Trans-Pecos Texas lose much of their water by underground seepage. Where such streams lower down their courses have cut down and flow over impervious bed rock, part or all of the water absorbed in their porous deposits higher up comes out again at the surface, forming permanent water holes or permanent flowing courses for at least some distances. Such conditions are common in the western part of the state especially between the longitude of San Antonio and El Paso but also notable in some other parts of Texas.

LARGE SPRINGS OF TEXAS

Many of the large springs of Texas are unknown because they are beneath river beds and therefore hidden from view. During dry periods most of the water in surface streams is derived from springs and seepages. A stream crosses a water-carrying stratum (or aquifer) on a fault at the point where such reaches the surface at lowest elevation and most at least of the water drains out to the surface there in obedience to the laws of gravity and of hydrostatics. The presence of these hidden springs can be determined by gauging stream flow at stations closely spaced in distance. A good example of a river's deriving most of its water supply from underground sources is afforded by the lower Pecos River. The Pecos where it leaves the Toyah basin downstream from the crossing of the Santa Fe (Orient) Railway carries in non-flood stages very little water and that very highly mineralized. In its lower course across the limestones and sandstones of the Edwards Plateau through which it flows down the dip of the rocks in a south-southeastward plunging syncline, its flow increases and the mineral content of its waters both changes in composition and decreases in amount. Water is added to the river by underground springs and seepage from the water-bearing rocks of the Edwards Plateau. The upper courses of Frio and Guadalupe rivers likewise derive most of their permanent water supply from the underground water of the Edwards Plateau, and the gravity springs are important along Llano, Pedernales, Medina, and Devils rivers. Devils River, only 50 miles long, has the largest minimum flow of any Texas river, amounting to about 245 second-feet, derived from springs.

Stream waters are muddy or turbid during times when most of their water supply is derived from rainfall or melting snow. Where their waters become clear most of the supply is derived from underground sources. Thus the spring-fed streams of the Edwards Plateau run clear most of the time, and the brownish but clear streams flowing "freestone" water in southeast Texas derive their supplies by seepage from sands and gravels.

Most of the great artesian springs of Texas are on the faults of the Balcones fault zone or faults displacing the sedimentary rocks of the Llano uplift. The Balcones fault zone springs are important in the belt from Austin to Del Rio. They derive their water from surface catchment areas of the Edwards Plateau in which the main water-bearing horizons are the basal Trinity sands and gravels, the Paluxy sands, and the limestones of the Edwards and Glen Rose formations, all of which belong to the Comanche division of the Cretaceous. Openings to the surface are afforded where the continuity of the rocks is broken in fault fissures at the south margin of the Edwards Plateau which is likewise the north margin of the Gulf Coastal Plain. O. E. Meinzer[2] gives the following gauging data of the discharge of some of these springs in second-feet, 1 second-foot equalling about 646,000 gallons per day:

Springs	Locality	Length of Record	Discharge Low	Discharge Highest	Discharge Approximate Average
Comal	New Braunfels	15 measurements	267	400+	350
Goodenough	12 miles southeast of Comstock, Val Verde County	5 measurements	181	256	222
San Marcos	San Marcos	6¼ years and other measurements	75	300+	135
San Felipe	Del Rio	8 measurements	85	150	115
San Antonio	San Antonio	6⅔ years and other measurements	0	200+	90
Las Moras	Brackettville	5 years and other measurements	0	60	34
Barton	Austin	17 months, plus 95 measurements	12	139	40

Perhaps the great fluctuations in flow are caused in part by much of the water flowing in continuous underground conduits or caverns in open channels dissolved out of limestone which permit free and rapid underground flow, the larger yields occurring shortly after

[2]Meinzer, O. E., Large springs in the United States: U. S. Geol. Surv., Water-Supply Paper 557, pp. 27–41, 1927.

periods of heavy rainfall over the catchment areas in the Edwards Plateau.

Spring and seepage conditions in the valley of Colorado River between Marble Falls and Austin are illustrated in the following table of stream gauging by the U. S. Geological Survey:

Situation	Second-feet	Date	Second-feet	Date
3½ miles above Marble Falls	3.0	Aug. 11, 1917	172	April 20, 1925
Mouth of Pedernales River	9.0	Aug. 9, 1917	225.1	April 22, 1925
Cat Hollow (Cox) Ford	9.2	Aug. 9, 1917	198.6	April 22, 1925
Lohman Ford	7.8	Aug. 9, 1917	223.5	April 23, 1925
Watson Ford	6.5	Aug. 9, 1917	233.4	April 23, 1925
Cameron Ford	7.9	Aug. 10, 1917		
Below Austin dam	20.5	Aug. 10, 1917		
¼ mile below Deep Eddy	24.2	Aug. 10, 1917		
Congress Ave. bridge, Austin	38.9	Aug. 10, 1917	257.4	April 24, 1925
Platts Ferry	63.1	Aug. 10, 1917		

The gaugings in August, 1917, were taken at the end of more than eight months of the driest period ever known in this part of the Colorado River basin. There must have been considerable loss by evaporation during the gauging period but the reservoir of the Austin dam was then empty and the natural flow of the river was passing through the dam; therefore, there was no evaporation from the reservoir surface. The gaugings in April, 1925, were taken during a dry winter and spring following a year (1924) when the rainfall was very close to the average annual at Austin but there was evaporation from the Lake Austin reservoir, the open-tank evaporation at Austin during April, 1925, being 6.1 inches, or more than one-tenth that for the entire year.

It will be noted that at the earlier date 6 second-feet (one second-foot equals 646,000 gallons per 24 hours) were supplied to the bed of Colorado River by springs in the fault blocks between Marble Falls and Pedernales River. Below the latter place, where the bed of the river passes over the Travis Peak sands and gravels, the intake area for a part of the artesian water of the Austin area, the river lost by seepage and evaporation 2.5 second-feet. Between Watson Ford and Austin dam 14 second-feet came in from river bed springs, and between the dam and Deep Eddy spring 3.7 second-feet were added from river bed springs. Barton Springs added 14.3 second-feet, from one-fourth mile below Deep Eddy to Congress Avenue bridge river bed springs added 14.7 second-feet, and between the latter place and Platts Ferry an additional 24.2 second-feet came from river bed springs. In the August, 1917, gauging period the river gained 60 second-feet from springs between Marble Falls and Platts Ferry. To this is to be added what was lost by evaporation in the 82-mile long stretch of the river, the open-tank evaporation at Austin for the month of August, 1917, amounting to the very high figure of 10.22 inches.

In the April, 1925, gaugings 26.5 second-feet were lost by seepage into the Travis Peak (Trinity) sands and gravels in the 6-mile course of the river below the mouth of Pedernales River, 53.1 second-feet having been added by river bed springs between Marble Falls and Pedernales River, 24.9 second-feet were added by such springs between Cat Hollow (Cox) and Lohman fords, 9.9 second-feet between Lohman and Watson fords, and 24 second-feet between Watson Ford and the Congress Avenue bridge of which 23.2 second-feet were supplied by Barton Springs. A total of 85.4 second-feet was added by springs between Marble Falls and Congress Avenue bridge, Austin. Apparently during the period there must have been a large amount of evaporation from Lake Austin, which would be the case if it happened to be windy.

If loss by seepage into the Travis Peak formation is taken into account the total flow of the springs in August, 1917, was 62.5 second-feet daily and in April, 1925, was 110.3 second-feet daily. The greater amount of seepage in April, 1925, is accounted for by the greater volume of river flow passing over a greater area of porous sands and gravels. The data serve to illustrate how the flow of springs varies with the rainfall.

The southern part of the Toyah basin in Pecos and Reeves counties has a number of large springs deriving most of their water from Comanche strata. Some of these are of the gravity type and others are fault springs of the artesian type. Phantom Lake, San Solomon Springs (at Toyahvale), Leon Springs, Comanche Springs (at Fort Stockton), Tunas Springs, Escondido Springs, and Pecos Springs are situated on an east-west line, which is probably a fault zone. Other large springs in Pecos County are the Santa Rosa, Monument, Agua Bonita and Sulphur springs.

There are numerous artesian springs on the faults of the Llano uplift of central Texas. In Llano County there are large springs at Wilbern's Glen on Little Llano River and on Honey Creek at the mouth of Honey Creek cove. In Mason County, springs of this type occur on Honey and Beaver creeks and James and Llano rivers. In Burnet County a notable fissure spring is that at Mormon Mill on Hamilton Creek. A number of fault springs are found in San Saba River and Cherokee Creek in San Saba County. There are other fault springs in Pedernales River and Cypress and Grape Creek valleys in Blanco County. The main artesian water horizons are the Hickory sandstone of the Cambrian and the Cambro-Ordovician Ellenburger limestone.

Every permanent or intermittent spring in the Rim Rock country of Presidio County is situated on a fault.

In the vicinity of the northernmost zone of faulting of the Balcones system, which is the zone forming the coastward limb of the Edwards Plateau, shallow wells within the various faulted blocks of the Trinity rocks will yield greater supplies of water than those on either side. The rocks in the faulted zone are more shattered, therefore having more open spaces affording both greater water supply and a higher rate of yield. In some cases the territory immediately coastward from these fault zones yields little water because its flow from intake areas farther inland on the Edwards Plateau is in part inhibited at the southern or southeastern limit of the fault zone and in part directed into more open spaces of freer circulation along the fault zone. Much wastage of the underground water, lessening both its head and amount, occurs in these fault zones through springs and seepages to the surface. Much of this spring and seepage water reënters the rocks where streams cross the porous, honeycombed, and cavernous Edwards limestone dipping coastwards in a narrow belt of outcrop at the coastward limit of the fault zone. Moreover, water from the Trinity rocks, the main aquifers on the Edwards Plateau proper, in crossing the outermost fault zones enters the downthrown porous Edwards beneath the surface. These are the reasons why the Edwards limestone is the most important artesian horizon in the San Antonio area.

HOT SPRINGS OF TRANS-PECOS TEXAS

Hot springs are found in Trans-Pecos Texas as follows: the two Indian Hot Springs at the west foot of the Quitman Mountains in the Rio Grande flood plain of southern Hudspeth County; a hot spring emerging from the Rio Grande basin gravels west of the Rim Rock between Candelaria and Ruidosa in central-western

Presidio County; Boquillas Hot Springs, near the junction of Tornillo Creek and the Rio Grande; and another one a mile farther up the river in the southern Big Bend country of Brewster County; and a hot spring beneath the river bed of the Rio Grande near the mouth of Stillwell Canyon, also in southern Brewster County. All are close to the Rio Grande, although the Presidio County hot spring is 6 miles east of the river.

All the Trans-Pecos hot springs are in areas in which igneous rocks outcrop. The Hot Well on the Southern Pacific Railroad in southeastern Hudspeth County and the underground waters of Chispa or Lobo Flat in southern Culberson and western Jeff Davis counties have compositions similar to that of the Indian Hot Springs. No analysis is available of the water of the hot springs in Presidio County and that of Boquillas Hot Springs is different in composition. The analyses of the hot springs and wells are as follows:

Analyses in parts per million

Ingredients	1	2	3	4	5	6
Bicarbonate (HCO_3)		551.2	244.6			
Carbonate (CO_3)	431.8	430.5		82.06	104.4	232.4
Sulphate (SO_4)	1208.61	1092.68	128.6	27.0	42.86	636.0
Chlorine (Cl)	2918.7	2803.24	30.88	14.9	20.92	119.3
Calcium (Ca)	174.5	187.0	7.38	5.78	14.0	234.9
Magnesium (Mg)	114.46	60.8	2.40	4.9	3.4	65.0
Sodium (Na)	2234.45	2477.12	162.15	69.61	91.61	168.5
Potassium (K)	tr.	122.77	n.d.	n.d.	n.d.	n.d.
Silica (SiO_2)	39.4	46.0	18.86	58.65	55.93	46.7
Nitrate (NO_3)			4.63	4.76	7.14	
Iron (Fe)	183.52					
Iron and aluminum oxides (R_2O_3)						3.9
Organic and volatile matter	95.0					
Total solids (parts per million)	7339.9	7771.0	599.80	267.58	340.51	1516.8

Index to Analyses

1. Water from Indian Hot Spring No. 1, analyzed by Turner Chemical Laboratory.
2. Water from Indian Hot Spring No. 2, analyst not known.
3. Water from Hot Well, analyzed by Willis W. Waite.
4. Water from Southern Pacific Railroad Valentine well, 716 feet deep, analyzed by C. S. Wilson.
5. Water from Southern Pacific Railroad Lobo well No. 5, analyzed by C. S. Wilson.
6. Water from Boquillas Hot Spring, analyzed by New Mexico Agricultural and Mechanical College.

The Hot Well is 1000 feet deep, the temperature of its water being 110° Fahrenheit. The Indian Hot Springs have temperatures of 120° Fahrenheit and 100° Fahrenheit. The temperature of the Boquillas Hot Springs water is 105° Fahrenheit and its rate of flow is 250,000 gallons daily. Temperature of the Presidio County hot spring is stated to be 114° Fahrenheit and its flow to be about 680,000 gallons daily.

In the analyses of numbers 3, 4, 5, and 6 in the table above, potassium has been included with the sodium, and in those of numbers 4 and 5 the oxides of iron and aluminum are included with the silica.

The percentage compositions of the above waters emphasize much more clearly the relationships of numbers 1 to 5 inclusive. To this table is added a final column for average sea water, and the percentage compositions given in the following table have been calculated after the deduction of the iron and aluminum oxides, silica, nitrate, and organic and volatile matter.

Percentage Composition of Above Water

Ingredients	1	2	3	4	5	6	7
HCO_3			42.36				
CO_3	5.9	5.97		40.12	37.66	15.43	0.207
SO_4	16.55	15.13	22.31	13.22	15.46	41.55	7.692
Cl	39.96	38.83	5.36	7.3	7.56	7.93	55.292
Ca	2.39	2.59	1.28	2.7	5.05	15.40	1.197
Mg	1.57	0.84	9.42	2.4	1.23	4.32	3.725
Na	30.57	34.31	28.15	34.08	33.05	11.19	30.593
K	tr.	1.70	n.d.	n.d.	n.d.	n.d.	1.106

It appears likely that 336 parts per million sodium bicarbonate ($NaHCO_3$) and 154.35 parts per million Glauber salt (sodium sulphate, Na_2SO_4), or nearly five-sixths of the total mineral matter, have been added from an igneous source to the Hot Well water. It is likewise probable that in the Indian Hot Springs No. 2 water there are 759 parts per million of sodium bicarbonate and 1295 parts per million of sodium sulphate, or 2054 parts out of a total mineral composition of 7725 parts, to be attributed to an igneous source. The remaining total salts, 5671 parts per million, assumed as the composition of the water in the sedimentary (non-igneous) rocks, compared with sea water ("connate" water) are given in percentage composition, thus:

	Indian Hot Springs No. 2	Average Sea Water
	Per cent	*Per cent*
CO_3	7.6	0.207
SO_4	4.4	7.692
Cl	49.43	55.292
Ca	3.12	1.197
Mg	1.05	3.725
Na	32.06	30.593
K	2.16	1.106

The resemblance is perhaps sufficiently striking to suggest very strongly the mixed igneous and connate origin of the Indian Hot Springs water, the part of non-igneous derivation of which contains 81.44 per cent of common salt (sodium chloride) and 7.8 per cent limestone (calcium carbonate), most of the balance being sulphates.

The Valentine and Lobo well waters belong to the same category. It is fairly evident that the Boquillas Hot Spring water contains a large amount (799 parts or 54.9 per cent) of calcium sulphate probably derived from gypsum which occurs in the Glen Rose formation. The theoretical composition of the Boquillas Hot Springs water would be as follows, the soda being the igneous contribution.

Ingredients	Parts per Million
$CaSO_4$	799.0
NaCl	197.0
Na_2CO_3	209.7
$MgCO_3$	159.8
$MgSO_4$	90.9

UNDERGROUND WATERS OF TRANS-PECOS INTERMONTANE BASINS

There are two large structural basins between mountain uplifts of Trans-Pecos Texas. The eastern, known as the Salt basin, extends from the southern end of the Sacramento Mountains in New Mexico southwards to the Chinati Mountains in Texas. The western, known in its northern part as the Tularosa or Otero basin and in its Texas extension as the Hueco Bolson or basin, extends from central New Mexico to a considerable but unknown distance into the Mexican state of Chihuahua. The Salt basin has no exterior drainage but the Hueco basin is crossed diagonally by the Rio Grande.

The southern end of the Salt basin, southwards from a relatively short distance north of the Texas and Pacific Railway, has underground water of excellent quality. North of a line running from the north base of the Baylor Mountains eastwards to the Seven Heart

Gap fault zone at the northwest base of the Apache Mountains the underground waters of the Salt basin, at least in its lower and more central area, are too heavily mineralized with common salt and calcium sulphate (gypsum) to be of value for irrigation. Some drinkable water can be obtained from wells sunk in alluvial fan deposits near the mouths of mountain canyons near the bases of the Sierra Diablo, Guadalupe, and Delaware mountains, except in the vicinity of Seven Heart Gap, where the underground water is heavily mineralized. About the best that can be said for the shallower waters nearer the center of this part of the Salt basin is that they afford a poor quality of stock water. The quality of the deeper waters of the basin is unknown because no attempts have been made to test them and at the same time cement off the shallower waters so as to prevent their contaminating the deeper. There is some possibility of leakage of the deeper waters to Pecos River to the east from the Salt basin near the New Mexico line through the Permian limestones and sandstones of the southern Guadalupe and northern Delaware Mountains in which the strata dip eastwards from the Salt basin towards Pecos River. One boring near the Figure 2 ranch headquarters is reported to have been still in unconsolidated valley fill at a depth of 1500 feet.

South of the east-west line already noted the quality of the underground waters, as shown by the wells at Van Horn and at Wildhorse railway siding, greatly improves. The Van Horn wells are reported to penetrate 600 feet of basin fill and the Wildhorse well 343 feet of the fill.

As far south as the Jackson well, in the middle of the south half of the northeast quarter of Section 20, about 2 miles northeast of Fay siding on the Southern Pacific Railroad, the general level of the ground water in the more central and lower part of the Salt basin is approximately between 3500 and 3600 feet above sea level. This level rises somewhat near the edges of the basin flat, as the surrounding mountains are neared.

The Eagle Flat basin is connected with the main Salt basin between Fay and Dalberg sidings on the Southern Pacific Railroad. The drainage area of the Eagle Flat basin extends as far west as the Sierra Blanca peaks and as far north as the southern scarp of the Sierra Diablo, its south limit being the summits of the Eagle Mountains. There is a local basin without exterior surface drainage which centers near Grayton siding, but from the vicinity of Torbert siding southeastwards the surface drainage goes to the main Salt basin. The underground water of Eagle Flat, although fairly deep, is of good quality as shown by wells at Sierra Blanca, Torbert, and Hot Wells. The water level at Torbert is reported to be 3620 feet above sea level (723 feet beneath the surface), and at Hot Wells it is at 3611 feet elevation. At Van Horn in the main Salt basin, the water level is at 3557 feet elevation. There is, therefore, probably underground connection of the water of Eagle Flat with that of the main Salt basin.

The southern continuation of the Salt basin south of Fay siding is generally known as Lobo or Chispa Flat. The Chispa Flat part of the bas'n has an estimated area of 1150 square miles (736,000 acres). The water level in the Lobo well of the Southern Pacific Railroad is 82 feet beneath the surface (3860 feet above sea level) which is about 200 feet higher than in the Jackson well 4 miles to the north. Therefore, it is probable that an underground impervious barrier crosses the north end of Chispa Flat somewhere between Lobo and Fay sidings and holds up the water level in Chispa Flat, the water draining northwards into Salt basin across this barrier. It is estimated that an area of about 65 square miles, or 41,600 acres, of the lowest part of Chispa Flat from near Lobo to the south is susceptible of irrigation by pumping, the underground water being of excellent quality. However, the flat is occasionally flooded by cloudbursts, and it will be necessary to construct ditches and embankments similar to those on the north side of the Southern Pacific tracks for part of the distance between Chispa and Lobo to protect the irrigable area from flooding. These ditches and embankments should start from the channel of Chispa Creek in the vicinity of Wendell section house and be carried along about the 4100-foot surface contour line on both sides the central flat to as far north as an east-west line in the vicinity of Fay siding. Only dirt has to be moved by a power ditcher and the expense will not be excessive. Construction of some concrete-floored and sided spillways with flood gates at various places will permit the use of some of the flood waters over the irrigable flat, thereby saving some of the costs of pumping. The ditches should have a slight gradient in the direction of Fay, sufficiently adequate to carry off rapidly the flood waters.

The northwestward gradient of the water level between Valentine (where the water-level is 4064 feet above sea level, 365 feet beneath the surface) and Lobo is 7.64 feet per mile but is higher near Valentine and becomes lower as Lobo is neared.

It is still unknown whether the deeper waters beneath Chispa Flat and the Hueco basin are under sufficient artesian head either to flow out at the surface or to rise within profitable pumping depths in the lower more central parts of the basins. It is probable that if water under such head exists beneath Chispa Flat it will be of a quality suitable for irrigation. This probability is somewhat less in the Hueco basin, but nothing in that basin yet known is unfavorable. In the main Salt basin north of the Texas and Pacific Railway the probabilities are not so good, for there are salt and gypsum deposits in the northern part of that basin in New Mexico, in the vicinity of Seven Heart Gap in Texas, and possibly beneath the Texas part of the main Salt basin.

The structure in these basins is favorable for the occurrence of deeper waters under considerable hydrostatic head. These waters are apt to occur in the lower part of the unconsolidated valley fill where the deposits are also probably quite porous sands and gravels to a considerable extent. In the Chispa Flat the underlying bed rocks beneath the basin fill are volcanic lavas, tuffs, agglomerates, and interbedded gravels. The last three are apt to be porous water carriers. Some of the consolidated sedimentary rocks underlying the valley fill in the Hueco basin probably carry water under artesian head but such appear now to be in the main quite deep, as will be shown in the section devoted to that basin.

No proper trials for these possibly deeper artesian or flowing waters have ever been made. It is true that a boring 1500 feet deep has been made in the main Salt basin near the Figure 2 ranch headquarters, another about 3000 feet deep has been drilled at Lobo in the Chispa Flat, and two, 4900 and about 3000 feet deep, have been drilled in the Hueco basin. But in none of these have the upper waters and dry sands and gravels been sealed off by tightly cementing a string of casing beneath them. Such cementation of casing is absolutely necessary in order to prevent leakage and loss of head of the deeper waters into the shallower water-bearing or porous, though dry, horizons, and it is absolutely necessary in any well drilled to obtain such deeper waters if they are found. Neglect of this fundamental precaution has harmed greatly or ruined many underground artesian conditions.

The thickness of the basin valley fill is known to be 872 feet at Valentine and 1180 feet in the Hughes Development Company Ball and Means boring about 1 mile north of Chispa section house but is not known in the lower and more central part of Chispa Flat in its northern part.

The history of the Hueco basin is probably not greatly different from that of the Salt basin, but the drainage of the former by the Rio Grande has disclosed to view more of its history. The Hueco basin is one of a number of former basins without exterior drainage which were formed when the present mountains originated by earth movements during the latter part of the Cenozoic era. These basins extend along the Rio Grande from San Luis Park in Colorado to Boquillas Canyon in Texas and comprise along the course of the river in Texas, in order downstream, the Hueco basin, the basin of Quitman Arroyo between the Quitman and Eagle Mountains, the basin extending from the head of Glenn Creek ("Green River")[3] to the Sierra Bofecillos near Redford, and the Big Bend sunken block, situated between the Grand Canyon of Santa Helena and Boquillas Canyon. Each of these four basins is partly in Mexico, across the Rio Grande, and very little is known of their Mexican parts.

On the northeast side of the Hueco basin, the rocks of the Hueco Mountains, of the Diablo Pláteau, and of the Finlay and Quitman mountains dip towards the basin. To the north of El Paso the lowest part of the basin surface lies near its west side, contiguous to the eastern foot of the block-faulted Franklin Mountains.

The underground water of the Tularosa or Otero basin of New Mexico does not reach the Hueco basin in Texas. The boundary between the underground waters appears to be in the vicinity of the Jarilla Mountains in southern New Mexico; at least the water to the south of these mountains is of better quality than to the north. Except in the vicinity of the Malone Mountains salt and gypsum are not known in the bed rocks of the Hueco basin. Good water is

[3]There seems to be some ambiguity concerning the usage of the term Green River. It appears sometimes to have been used for Quitman Arroyo and at other times for Glenn Creek The latter is in the intermontane basin between the Eagle and Van Horn mountains, in the southeast corner of Hudspeth County.

found in the railroad well at Newman, close to the Texas line, on the mesa in the vicinity of Fort Bliss, and in Carpenter Bros. and Sharpe's well 10 miles northeast of Clint. The water level in the well last mentioned is 345 feet beneath the surface, in the Fort Bliss wells it was originally about 177 feet, and in the Newman well it is 272 feet. This water is in sands and gravels which range up to more than 400 feet in thickness which overlie the lake deposits. After the lake was drained the overlying sheets of sands and gravels were washed into the basin areas from the adjoining mountains. The Rio Grande, both above and below El Paso, has now cut through these sands and gravels into the underlying lake deposits.

The fine-grained sands and clayey silts comprising the lake deposits are of great thickness, but no well in the Hueco basin has yet gone deep enough to reach their base. The Cinco Minas or Hueco Basin Oil Company well near Newman was still in them at a depth of 4910 feet, the 2300-foot well near Fort Bliss stopped in them, and the Silix No. 1 Malone well near Tornillo was still in them at over 3000 feet depth. Sands and gravels probably occur in them in their lower part, near their base, and these probably contain water under considerable artesian head which may flow out at the surface in some places. The possible quality of the water is not predictable. Some disseminated gypsum occurs in the upper or outcropping part of the lake beds.

The International Water Company drilled a well 2285 feet deep in Section 17, Block 81, Township 2, near Fort Bliss. No water was found in this well below a depth of 450 feet. This is not surprising because most of the lake beds are fine-grained non-porous sediments, except near the base where coarser detritus derived from the then recently uplifted and rapidly eroded mountains will probably be found to rest on the consolidated bed rocks.

The underflow in the valley of the Rio Grande, derived from downward percolation of the water from the river into its alluvial deposits, is of much poorer quality than the mesa water, although it is used successfully for irrigation. The underflow water is relatively high in sulphates and chlorides, derived from Permian salt and gypsum deposits in New Mexico, which perhaps extend also into Texas in the Mesilla Valley west of the Franklin Mountains to the north of El Paso. The Rio Grande underflow, through the bed rock pass of the river 4 miles above El Paso, amounts only to 50 gallons per minute. Since the extensive irrigation of the valley lands below the Elephant Butte reservoir, it is likely that the underflow has decreased in amount and at the same time has become more highly mineralized.

The intermontane alluvium-filled valley of Quitman Arroyo probably is connected with the Hueco basin around the south end of the Quitman Mountains, which end in Chihuahua a short distance south of the Rio Grande. There is possibly deep artesian water in the vicinity of Quitman Arroyo in the area near the Rio Grande. The intermontane area of Quitman Arroyo is bounded on the east by a mountain rim, which is the Devil Ridge and Eagle Mountains in Texas but extends far beyond the Rio Grande in the various Pilares ranges of Chihuahua, and the general mountain uplift may continue to beyond the Rio Conchos. An investigation of the extent and limits of this great intermontane basin in Chihuahua is very desirable.

Another great intermontane basin floored by lake beds extends from the head of Glenn Creek between the Eagle and Van Horn mountains, on the north, to Redford, beyond the mouth of Alamito Creek, on the south. Much of this basin lies in Chihuahua on the Mexican side of the Rio Grande. From Pilares, Texas, to about 10 miles south of Candelaria the bottom of the basin lies on the Mexican side of the river and there is, furthermore, little irrigable land, except in the river floodplain, on the Texas side of the river. However, from about 10 miles south of Candelaria downstream to Redford the basin is much wider and there is more cultivable land on the Texas side. There is a possibility that deep artesian water may exist relatively near the river here in the Texas part of the basin. Alluvial deposits of gravel and sand 1000 feet thick are exposed in Pinto Canyon on the north side of the Chinati Mountains. These are good aquifers and may supply artesian water to wells near the mouth of Pinto Canyon.

The Santa Fe Railway has two flowing artesian wells of moderate depth and excellent water at Plata and Casa Grande along the middle course of Alamito Creek, where, unfortunately, there is little cultivable land. This flowing water occurs in the trough of a large syncline in volcanic rocks. A zone of uplift extends southwestwards from Shafter to beyond Alamito Creek to the west of the Black Hills. This may bound to the south the artesian basin of middle Alamito Creek, although it is not certain. If it does, artesian water may be found along Alamito and Black Hills creeks and between them in the area north of the Black Hills. If, however, the syncline continues to the south, the area of possible artesian water is likely to extend to beyond the Rio Grande along the lower Alamito, Black Hills, and Torneros creeks. Much can be learned about these possibilities by further geologic investigation of the area. Farther north on the railroad at Tinaja, 9 miles south of Marfa, the water level is 74 feet beneath the surface.

The Santa Fe Railroad boring at Presidio entered the lake clays at a depth of 68 feet and entered the first sand, with salty water, at a depth of 1320 feet. This salty water rose to within 110 feet of the surface.

The Big Bend sunken block extends from the southern part of Green Valley on the north southwards to at least the south end of the Sierra Encantada in Mexico, which is 80 miles beyond the southernmost point of the Big Bend in Texas. In this sunken block most of the formerly existent lake beds have been eroded away, and the chances for deeper underground waters are mainly restricted to bed rock Cretaceous and in some few instances to Tertiary volcanic rocks. The sunken block in Texas is about 30 miles wide; it is bordered on the east by the Carmen Range and on the west by the Solitario and Mesa de Anguila-Sierra Ponce uplifts. The bed rock structure of the sunken block is quite complicated and there are numerous igneous intrusions. The Upper Cretaceous rocks contain in general fairly large amounts of soluble mineral matter, and the water they carry is probably for the most part of poor quality. The thick Edwards-Georgetown and Glen Rose limestones and the basal Cretaceous sands and gravels may contain waters of better quality, though generally high in carbonate of lime, which, however, is not deleterious except for boiler use. However, the Glen Rose may have considerable gypsum or anhydrite. Igneous intrusive rocks of intermediate and basic composition occur which may afford sources of deleterious sodium alkalies in the Lower and Middle Cretaceous waters.

UNDERGROUND WATER STORAGE IN TRANS-PECOS TEXAS

The amount of evaporation from a body of water open to the air varies from 4 times the total rainfall in the east part to about 10 times the total rainfall in the west part of Trans-Pecos Texas. A layer of water from 5 to 7 feet in depth will be evaporated annually from a reservoir. Loss from open reservoirs is therefore so great that underground storage of water is very desirable wherever possible. This can be accomplished by holding the water in gravels, boulders, and sands composing the alluvial deposits of a stream above a place where the underflow is dammed off by either a natural rock barrier or an artificial one. Permanent water holes, springs, and permanent running water for short courses along stream channels occur at places along some Trans-Pecos creeks when they have cut down to impervious rock in their channels. In some places dams can be constructed upon the impervious rock across the channels, thereby both storing a part of the flood water and conserving the underflow from the porous stream deposits higher up the stream courses. This underflow, after appearing at the surface where such impervious rock barriers are found, is partly lost by evaporation, and the remainder sinks into the porous alluvial deposits farther down the course of the stream. Natural and artificial dam sites occur largely in the mountain sections of stream courses but they also occur lower down the courses of some streams, in the lowland flatter areas where lime (calcium carbonate), known as caliche, has tightly cemented locally sands, gravels, or boulders. Reservoir basins along those sections of the streams where the gradient is high are apt to fill rapidly with débris. It is true also that cloudbursts, or floods from cloudbursts, or exceptionally heavy rains often carry large loads of detritus out into the lowlands courses considerable distances from the mountains. Cloudbursts may thus affect any part of a stream course in western Texas. But even if a reservoir basin is filled entirely with detritus much water can be stored underground in the filled basin, provided the filling material consists mainly of coarse detritus and not impervious clay or silt. This water can be drained off by an outlet in the lowest part of the dam and utilized when needed.

In those places where constrictions or "narrows" with valley walls and floors of impervious rock occur, dams are feasible, provided sufficient amount of watershed and storage basin exists above the dam sites. The stream channel and lower cross section of the valley may be floored with boulders, gravels, and sands, and yet impervious rock may occur at no great depth beneath the surface. At such localities the alluvial deposits may be trenched across the valley to the underlying rock and a concrete dam constructed on the solid rock. The dam may, if possible and advisable, be built to a height greater than the original surface of the valley deposits. This will depend, of course, on the nature of the site. Such dams, unless built to a considerable height above the level of the valley fill, need not be very wide, but it is important that they be made of strong and dense concrete and built entirely across the valley and be everywhere floored and walled by solid and impervious rock. Neglect of the precautions will mean ultimate failure of the dam.

A few sites along Trans-Pecos drainage courses where underground storage of water is possible have been noted, although none of these have been as fully investigated as is necessary or desirable. They will be mentioned because they afford some instances of the possibilities. Doubtless a number of others, equally good or better, can be found.

Some sites were noted in the Marathon basin of Brewster County. One is on Maravillas Creek at Maravillas Gap in the southwest part of the basin. Here the creek cuts through a ridge of impervious bed rock, about 1 mile northeast of the end of the ridge. The creek has a large drainage area above the gap and there is considerable lower land south of the gap which is irrigable. It is, however, possible that part of the underflow from the creek basin escapes to the southwest beyond the west end of the ridge through which the gap is cut. However, it is probable that at least some of the underflow can be stored underground above the gap by trenching to the base of the gravels in the gap and constructing a dam on the underlying bed rock across it. About 2 miles west-northwest of Haymond station on the Southern Pacific Railroad there is a narrows on San Francisco Creek which is floored by impervious bed rock. Upstream from this narrows there is a rather extensive flat with good soil under which ground water exists only a few feet beneath the surface. Here is an instance of a natural rock dam causing storage of underground water in the drainage basin above it. In some of the flat, subirrigation of alfalfa is possible if the roots of the plants succeed in reaching the water beneath, or shallow pumping wells are possible, at least to irrigate the land until the alfalfa roots reach the underground water. In places close to the creek the water is so shallow that alfalfa might be drowned out ultimately. A dam across the narrows would furnish some water for irrigation in the creek valley below. Some water can be impounded above the narrows at Woods Hollow tank and also at the picnic grounds on Peña Colorada Creek. Other storage sites for small quantities of water occur in the Marathon basin, as, for example, at the Rock House narrows just below the junction of the Maravillas and Dugout creeks.

There is a possible dam site on Calamity Creek about 2½ miles above the Neville ranch house and east of the Alpine-Terlingua road, although the nature of the bed rock is not known. Some of the larger drainages, such as those of Terlingua, Alamo, and Alamito creeks may afford other sites for storage.

TOYAH BASIN

The Toyah synclinal basin includes all Reeves and Loving counties, the northwest half of Pecos County and the western parts of Ward and Winkler counties. This basin is bounded on the east by the uplift on which is situated the line of oil fields in Winkler and Ward counties. It is bordered by the mountains on the west and south. The deepest part of the structural basin extends from northeastern Reeves County northwards in the vicinity of the boundary between Loving and Winkler counties. The deeper Permian waters underneath the basin carry such large amounts of salt and calcium sulphate that they are unfit for irrigation. However, in northern Pecos County and perhaps in places in eastern, southern, and western Reeves County there is possibility of obtaining water of suitable quality under artesian head in the Basement sands and gravels of the Cretaceous and possibly in the next underlying strata of the Triassic. A flowing well 194 feet deep, 8 miles north of Fort Stockton, apparently derives its water from the Cretaceous.

There are flowing wells at Toyah and in the vicinity of the town of Pecos. The flowing well at Toyah is 832 feet deep and is reported to have penetrated throughout gravels and sands of probable alluvial fill. The flowing wells in the vicinity of Pecos range from 90 to about 300 feet deep. These extend from 3 miles north to 2 miles west and 6 miles south of the town. The upper flow is strongly saline, the salt water horizon being underlain by impervious clay, below which flowing water is found in gravel. The Humble Balmorhea Live Stock Company No. 1 boring, about 5 miles south of

Pecos, probably penetrated 1395 feet of sands, silts, and gravels before reaching the bed rock. The Exploration Company No. 1 Kinney boring, about 10 miles northwest of the town, appears to have been in sand, silts, and gravels to a depth of 1695 feet, perhaps reaching Permian bed rock at that depth. This area of thick fill composed of alluvial deposits extends to the western margin of the Wheat oil pool near Mentone (Porterville), Loving County, and 10 miles or more farther to the northwest. Possibly it extends westwards to beyond Toyah, and southwards to Toyah Lakes. The water is fairly highly mineralized but is usable for irrigation.

Another area of deep alluvial deposits, averaging perhaps 6 miles in width, extends from the New Mexico line near the northwest corner of Winkler County south-southeastwards across western Winkler and central Ward counties to the vicinity of Pecos River. This area is partly upon and partly west of the line of uplift forming the east border of the Toyah basin. The Sun Company No. 1 Sealy boring near the Ward-Winkler county line was in the Cenozoic fill deposits to a depth of 2000 feet. This area contains water under artesian head, but the quality is unknown to the writer.

It is probable that these two areas of deep alluvial deposits are situated where extensive ground settlement has taken place upon solution of underlying salt, anhydrite, and potassium beds in the Permian. An extensive area of solution of these saline residues is known to lie between the eastern base of the Delaware Mountains and the artesian basin along Pecos River. The Pecos River from some distance northwest of Mentone downstream to the vicinity of the mouth of Toyah Creek is flowing near the northeast limit of the area in which solution has probably taken place. Its course in this belt is probably to be attributed to depression caused by ground settlement. The river water carries very large amounts of salt and calcium sulphate, probably in part taken by solution from the underlying Permian beds.

WESTERN EDWARDS PLATEAU REGION

Mr. M. E. Roberts has kindly supplied in summary form the following data which are considerably more comprehensive than those heretofore published concerning this region.

Classification of the major Comanche water-bearing horizons of the Western Edwards Plateau region

County or part of county	Georgetown; + 300	Georgetown; + 240	Edwards; + 160	Edwards; + 100	Paluxy; — 10	Paluxy; — 60	Glen Rose; — 160	Glen Rose; — 260	Glen Rose; — 340	Travis Peak; — 800	Glen Rose; — 1300
First province											
Nolan, south						*					
Coke, west Sterling, to east					x	*					
Sterling, west					*	*	*				
Glasscock					*	*	*				
Midland, south						*	*				
Ector, east					x	*	*				
Upton					x	*	*				
Reagan				*	*	*					
Second province											
Tom Green, south				*	x	*					
Schleicher, east	x			*							
Concho, south					x						
Menard, west					x						
Menard, east					x	x	*				
Sutton, east				*							
Kimble, west					x						
Third province											
Kimble, east					x	*	*				
Sutton, west	x										
Schleicher, west				*		*	*	*			
Irion				*	*	*	*				
Crockett				*	*	*	*				
Terrell, north				*		*		*	*		
Pecos, east					*	*	*				
Pecos, west				x	*						
Fourth province											
Terrell, south						*	x	*			*
Val Verde, north			x			x			*	*	
Edwards and Real	x		*				x		*		
Kerr, south and west			*		x		x	*	*	*	
Bandera, west					x		*			x	
Uvalde, north, Kinney, north		x				x	x			*	
Fifth province											
Uvalde, south	*	*	x		x		*				*
Val Verde, south, Kinney, south		*		x			*				*

Explanation.—*, many water wells and large volumes; x, fewer wells and smaller volumes; +, —, distance of water-bearing horizon in feet above or below base of Comanche Peak limestone. Only persistent horizons are shown.

Some Remarks on Classification of the Major Comanche Water-Bearing Horizons of the Western Edwards Plateau Region

Area covered is 35,000 square miles comprising 25 counties, north to Nolan, south to Maverick, east to Kerr, and west to Pecos. Area is divided into five provinces, as given in the table. Four hundred sixty wells were used and also a considerable body of water well data in Pecos, Midland, Schleicher, and Edwards counties. In absence of field work on this particular problem, the use of topographic benches in correlation of wells was of considerable assistance.

Experience with shallow water well data all over the area indicates that many weak Washita and Fredericksburg water occurrences are not recorded in records of wells drilled for oil, either in geological or scouting departments, particularly in the third province and to some extent in the fourth.

The source of most of the waters is chiefly within the area and to the north and to the west of the area.

There are very few, if any, artesian flows unless they be in the fifth province, where the data are less complete, and unless there are local fortuitous occurrences in the third and fourth provinces.

Paluxy, and especially Edwards and Georgetown, water sheets show widely uninterrupted geographic distribution and great uniformity in intervals above and below known stratigraphic markers.

Paluxy waters are consistently the most potable of all waters, although there are local occurrences, such as south Tom Green County and western Pecos County, with sulphur waters in the Paluxy.

Much greater vertical range of waters in the fourth and especially the fifth provinces directly reflect greater thickness of strata above the Georgetown and especially below the Paluxy break.

Georgetown waters are only strongly developed in the fifth province where the top is buried from 600 to 1500 feet below the surface. Many water wells in the second and third provinces have been drilled only to the weak and spotted Georgetown water sheets, and the yields in these wells are consequently light.

The plus 100 foot water above the Comanche Peak is best developed in the central part of the plateau in chiefly the second and third provinces. This horizon marks a distinct break in sedimentation. The limestone sheet immediately under the break is a topographic bench marker, many benches being plateau-like in aspect, in many counties in the first, second, and third provinces. This water-bearing horizon is frequently a thin sand, as shown by samples in a number of counties and by surface exposures in Pecos County. The interval to the base of the Comanche Peak limestone varies from 80 to 120 feet but is remarkably consistent at 100 feet for most of the area. This is the "Trinity sand" of much early water well work by many companies in the region. This break marks the surface over large areas in Upton, Midland, and Glasscock counties and parts of Ector County. The break gradually dies out to the south in Kerr, Edwards, and Val Verde counties. It is found over approximately 15,000 square miles.

The minus 10 foot Paluxy waters are found in the first sand of the Paluxy, under the Walnut where present and, if not, directly under the Comanche Peak. They are best developed in the first and especially the third provinces and again in these provinces are most prolific in synclinal regions.

The minus 60 foot Paluxy sand is the most consistent water sheet of the Edwards Plateau region proper. It yields consistently the largest volumes of water and has the fewest and smallest dry spots. It is found in a broad belt several hundred miles wide which parallels the final strand line of the Paluxy to the northwest of the area being considered. The occurrences of the water diminish directly with the decreasing sand content of the Paluxy break as the Rio Grande embayment is approached. The fourth and fifth provinces are essentially to the south of this water horizon. The south limit is marked by a line from Gillespie to Kerr, to Edwards, to Val Verde counties, roughly parallel to the Balcones fault but north of it.

The minus 160 foot Paluxy sand is a consistent and large producer in especially the first and third provinces. The interval to the base of the Comanche Peak is somewhat less in the first province. It is probably Glen Rose in age in the fifth province, where it is associated with black shales, anhydrite, sand, and numerous oil showings.

The Glen Rose water horizons are less regular than the foregoing, although there are at least four water horizons which are each consistent over portions of the eight southern counties of the area. Along the strike of deposition in the various stages of the Glen Rose the waters show much greater regularity. Glen Rose waters are apt to be contaminated with salines.

SHALLOW WATER IN UVALDE COUNTY

Data concerning ground water conditions in Uvalde County are given in the following publications:

Getzendaner, F. M., Mineral resources of Texas: Uvalde, Zavala, and Maverick counties (preprint): Bureau of Economic Geology, pp. 93–111, 1931.

Vaughan, T. W., Description of the Uvalde quadrangle: U. S. Geol. Surv., Geol. Atlas, Uvalde folio (No. 64), 7 pp., 1900.

Survey of the underground waters of Texas: U. S. Geol. Surv., Memorandum for the Press, pp. 11–12, Feb. 16, 1931.

The Balcones escarpment, forming the south and southeast limit of the Edwards Plateau, was produced by combined faulting and tilting movements in late Cenozoic times. As a result the Edwards Plateau was uplifted with reference to the Coastal Plain immediately adjacent on the south and southeast. Thereupon the streams flowing from the Edwards Plateau to the Coastal Plain rapidly eroded their valleys and carried the eroded débris down their courses and spread it out on the Coastal Plain lowlands in the form of alluvial fans or land deltas. The alluvial deposits are known as the Uvalde and Leona formations.

The largest of these land deltas was built up by the Rio Grande in southernmost Val Verde County, the southwestern half of Kinney County, and the northern part of Maverick County. In Uvalde County the alluvial deposits swept from the Edwards Plateau coalesced in a fairly broad belt along Nueces, Dry Frio, Frio, and Sabinal rivers.

The surficial Uvalde and Leona stream deposits conceal so much of the underlying bed rock that much of the structure of the latter is unknown in detail. The general structural conditions, so far as known, are well summed up by Getzendaner[4] as follows:

The principal structural feature of Uvalde County is a complicated system of faulting and folding, most of which is probably related to the Balcones fault system. Reference to a geologic map of the state, particularly to Vaughan's map of the Uvalde quadrangle,[5] will show a marked extension of the Comanchean southward from the Edwards Plateau, the axis of this extension passing about 3 miles east of the town of Uvalde. In an unpublished manuscript, G. Jeffrey has aptly named this the "Uvalde Salient." Measured on the exposed Comanchean alone, the Uvalde Salient extends 11 miles southward from the main line of the Balcones fault, and is about 7 miles wide at the town of Uvalde. On younger beds both dimensions are much greater. Attention is directed to the fact that there is very little displacement along the line of the Balcones fault where the Uvalde Salient departs from the main Comanchean province to the northward. There is evidence that even some of the displacement shown there by Vaughan's map is due to the collapsing of cavern roofs in the Edwards rather than to deeply penetrating faults. On the other hand, at the southern end of this Comanchean extension, Escondido (Navarro in age) is downthrown on a level with the Edwards limestone by a zone of faulting 1 to 2 miles wide and 8 miles long, the displacements aggregating about 1300 feet within less than two miles.

Whether this southern fault system is actually identical in time and cause with the Balcones or not, it gives an interesting view of existing conditions to consider it as an offset of the Balcones fault, the two lines being connected on either side of the Uvalde Salient by cross faults, those on the eastward striking north and northeast and being downthrown on the east and southeast sides, and those on the westward striking nearly north and south and being downthrown on the west side. According to this view the Uvalde Salient would be an eroded southern extension of the Edwards Plateau. The Uvalde Salient is arched as well as faulted. The respective eastward and westward dips extend far beyond the cross faults mentioned, and the arching extends southward into the Tertiary of southern Uvalde and northern Zavala counties several miles beyond the southern faults mentioned. The section, Figure 11,[6] crosses this salient.

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[4]Getzendaner, F. M., Mineral resources of Texas: Uvalde, Zavala, and Maverick counties (preprint): Bureau of Economic Geology, pp. 97–98, 1931.

[5]Vaughan, T. W., Description of the Uvalde quadrangle, U. S. Geol. Surv., Geol. Atlas, Uvalde folio (No. 64), map, 1900.

[6]Figure not reproduced

The following is quoted from the "Survey of the underground waters of Texas."[7]

The Edwards and associated limestones take in water in much larger quantities than any other formations in the area. The upper beds consist of highly fractured limestones, which in places are cavernous. All the streams that cross the outcrop of these fractured limestones lose water heavily. Stream measurements indicate that the streams of Uvalde County and the western part of Medina County, of which the Nueces, Frio, and Dry Frio are the largest, probably lose an average of not less than 100,000 acre-feet annually into these limestones. The records show that when the Nueces River is carrying less than about 100 second-feet it disappears completely in crossing these limestones. During the flood of May 28 to June 2, 1929, an average of approximately 680 second-feet, or about 300,000 gallons a minute, disappeared from the river in the stretch of 15 miles between the Laguna and Uvalde gaging stations, which includes the outcrop of the most permeable limestone. A part of the water that disappears into the limestone is brought to the surface, or nearly to the surface, by extensive folding and faulting or by upward leakage through fractures in the overlying impermeable rocks that have been baked and hardened by igneous action in the locality of Uvalde and farther south. Within this zone springs appear in the bed of the Nueces River southwest of Uvalde, which sometimes have a discharge of 30 second-feet or more, and springs also appear in the bed of the Leona River south and southeast of the town, which at times discharge as much as 10 second-feet. The springs along the Nueces are fed in part from water stored in the gravel during floods, but they derive most of their supply from the limestones. Practically all the water discharged by the springs along the Leona River has its source in leakage from the limestone. The springs represent only a part of the total leakage, the greater part of it being discharged underground into the gravel underlying the flood plain of the Nueces and adjacent terraces and into the gravel, sand, and silt of the Leona formation, which has a widespread occurrence in the locality of Uvalde and in the valley of the Leona River from Uvalde to the junction of the Leona with the Nueces. The water moves slowly down the valley in these unconsolidated deposits and under natural conditions is gradually transpired by deeply rooted shrubs and trees, of which the live oak and pecan are outstanding examples. The question as to the total leakage from the limestone is still under consideration and will be given further study.

The Edwards limestone and associated formations occur at depths to which it is practicable to sink wells in a relatively narrow belt along the main outcrop (see map 2)[8] and in an area of considerable size in the vicinity of Uvalde. Farther south they pass to great depth. In these localities they yield water that is somewhat hard but fairly suitable for domestic use. The cities of Uvalde, Sabinal, and Hondo obtain their public supplies from wells in these

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[7]Survey of the underground waters of Texas U. S. Geol. Surv. Memorandum for the Press. pp 11-12, Feb. 16, 1931.

[8]Map not reproduced.

formations. In the vicinity of Uvalde 16 irrigation wells obtain their supplies from the limestone or the overlying Austin chalk or Leona gravel. Some of these wells have a capacity of 1000 gallons a minute or more.

The head of the underground water in the Edwards, Glen Rose, and Travis Peak formations is higher than the ground surface where the Balcones faults reach the latter at the base of the Edwards Plateau. On the downthrown Coastal Plain side of the faults the porous part of the rock section is already full of water. Therefore, the water rises to the surface and is absorbed in the porous gravels and sands of the Uvalde and Leona and of the more recent deposits along the stream courses. A large part of this water reënters the Carrizo sand reservoir farther south yielding an artesian supply to wells in Zavala, Dimmit, Atascosa, and Frio counties. Thus the water passes from one formation into another and again into a third, the same process taking place to some extent to the south of the Balcones escarpment in a number of places in the 250 miles between the Rio Grande and Colorado River.

GROUND WATER IN THE SAN SABA AND PEDERNALES RIVER VALLEYS

A number of downfaulted blocks occur in the valleys of the rivers and tributary creeks in McCulloch, San Saba, Gillespie, and Blanco counties. Porous horizons in the Ellenburger group and in the Cap Mountain and Hickory formations contain water under artesian head. This is brought to the surface in fissure springs. Considerable land in these valleys can be irrigated for the production of fruit, nut, and vegetable crops by water supplied from wells.

STAKED PLAINS

The Llano Estacado or Staked Plains province is situated in the central and deepest part of the greatest syncline in the southwestern United States. This syncline extends from the easternmost mountain ranges in New Mexico eastwards to beneath the Cretaceous exposures of central Texas between the 97th and the 98th meridians. It is limited to the north by a line of uplifts extending from the Arbuckle through the Wichita Mountains to the Canadian River valley in the Texas Panhandle. Its south boundary extends from the Glass Mountains of Brewster County, Texas, eastwards to the Llano uplift in the Colorado River valley in San Saba, Blanco, and Burnet counties.

On the southwest it is separated from the Toyah synclinal basin to the west by a line of uplift which extends from the Hobbs oil field in Lea County, New Mexico, south-southeastward to beyond Pecos River in Texas.

The Llano Estacado is underlain by water-bearing strata of various ages, of which those nearest the surface are Permian, Upper Triassic, Cretaceous, and later Cenozoic. The Permian waters of the upper thick zone of salt and anhydrite are highly mineralized. We are concerned here, mainly, with the history of the area after the Permian time and with the deposits formed after the Permian and preserved to the present time.

The Upper Triassic sediments resting upon the Permian are non-marine and for the most part were deposited by streams. These have their maximum thickness of about 1850 feet in the deepest part of the syncline. In marginal flank areas, they are thinner, the upper strata having been eroded away. The Comanche Cretaceous deposits rest on various horizons of the Triassic, indicating that much erosion as well as downfolding of the Triassic beds into the syncline took place before the Cretaceous strata were deposited. However, to the southwest, towards the mountains, folding and perhaps faulting movements took place subsequent to the Cretaceous, as indicated by the Cretaceous deposits being at approximately 1500 feet higher elevation on the Concho-Pecos divide in Ector County than they are where borings have penetrated them beneath the present surface in northern Pecos County.

Mr. M. E. Roberts has very obligingly prepared for the writer the two maps here reproduced (figs. 20 and 21) which give structural contours on the base of the Upper Triassic strata and thicknesses for the Triassic, the generalized section for the Triassic, and data on thicknesses of the Cretaceous and on water horizons of the Triassic. Inasmuch as these data were hurriedly prepared by Mr. Roberts from well sections long distances apart, there is no pretence made that they are accurate in detail, and they are meant to give only a very generalized conception of conditions. Drilling samples from horizons higher than the Permian have been saved from relatively few borings on the Llano Estacado.

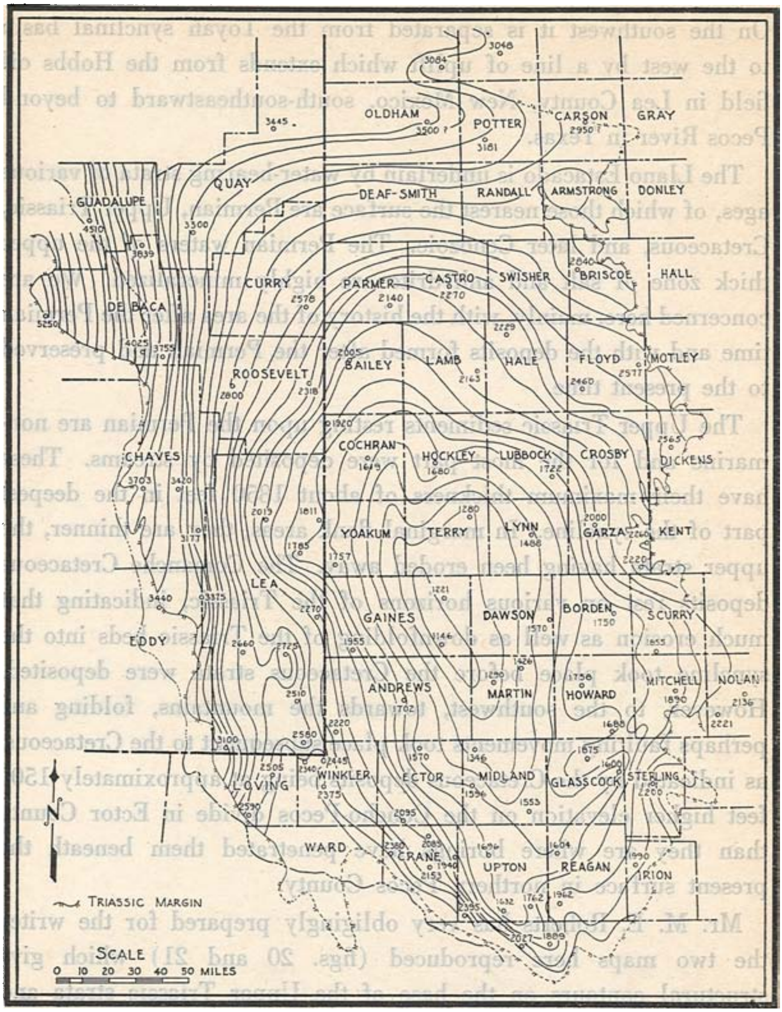

Fig. 20. Map showing the structure of the Triassic rocks underlying the Llano Estacado, with 100 foot contours on base of Triassic. Contributed by M. E. Roberts.

A comparison of the thickness map of the Triassic, the structural map of the base of the Triassic, and the known thicknesses of the Cretaceous indicates that the greatest thicknesses of the Triassic and Cretaceous are situated in the general area of the lowest structure or trough in the syncline of the Triassic beds. It is suspected that

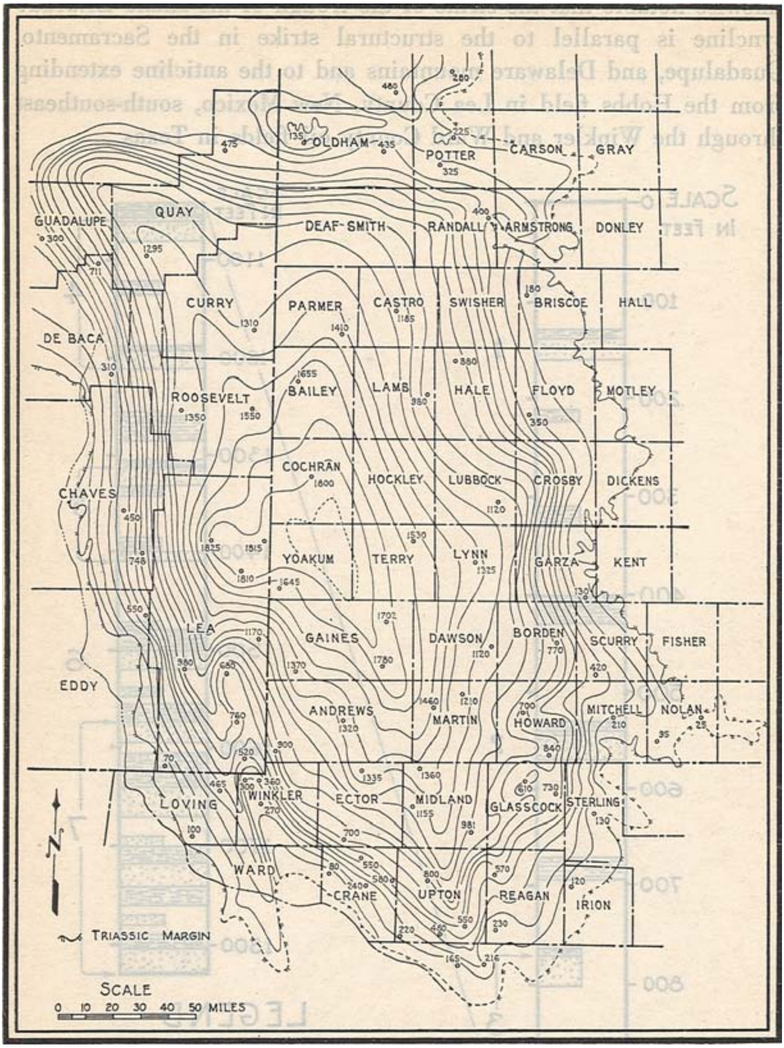

Fig. 21. Map showing thickness of Triassic rocks underlying the Llano Estacado. Lines at 100-foot intervals. Contributed by M. E. Roberts.

if drilling samples were available from more borings in the heart of the syncline, this general correspondence would be even more marked, although it is true that irregularities in thicknesses of both Triassic and Cretaceous caused by varying amounts of erosion previous to the deposition of overlying strata necessarily occur. It is likewise notable that the strike of the trough of the Llano Estacado syncline is parallel to the structural strike in the Sacramento, Guadalupe, and Delaware mountains and to the anticline extending from the Hobbs field in Lea County, New Mexico, south-southeast through the Winkler and Ward County oil fields in Texas.

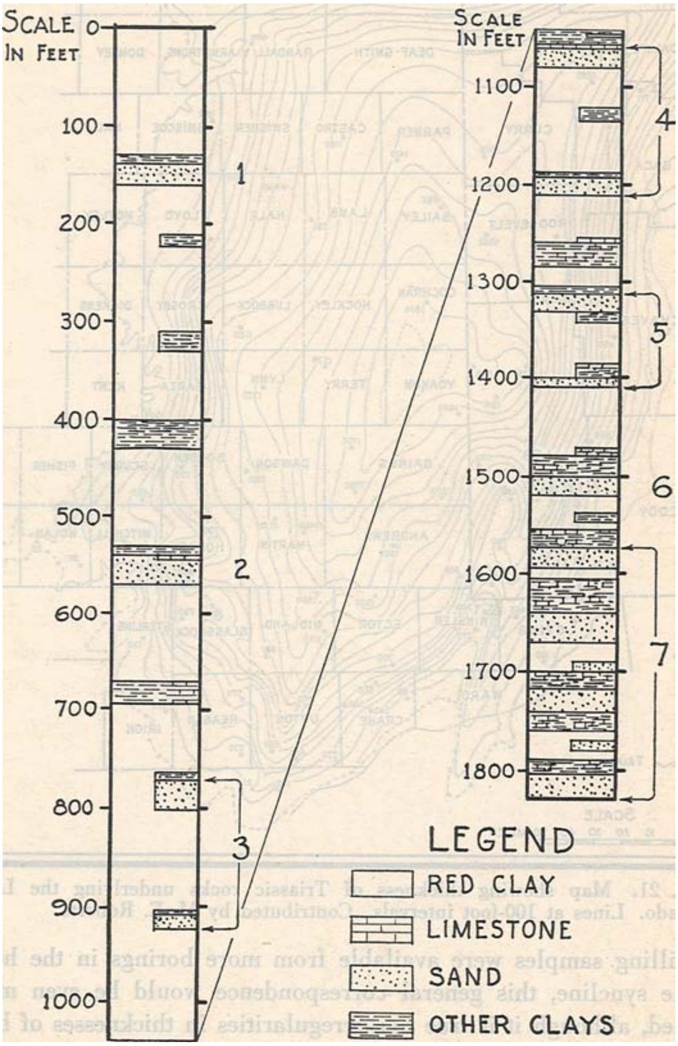

Fig. 22. Columnar section of Triassic rocks underlying the Llano Estacado. Contributed by M. E. Roberts.

The nature of the Triassic rocks is given in the accompanying generalized section (fig. 22). The lower division, characterized by being more sandy and gravelly, is noteworthy in generally being about 255 feet in thickness throughout the syncline, although varying within the limits of from 100 to 280 feet. This general uniformity in thickness would appear to indicate that it was deposited over a sub-level area and not in a trough produced by post-Permian and pre-Upper Triassic folding. In the upper or more shaly division of the Triassic there appear to be more sands in the western part of the Triassic. The maximum thickness of the Triassic, about 1850 feet, is in Yoakum, Cochran, and Gaines counties, Texas, and in northeastern Lea County, New Mexico.

The following notes on the sands in the Triassic have been furnished by Mr. Roberts:

First zone.—There is only one sand in this zone and it is only developed in that part of the basin where the Triassic is thickest.

Second zone.—Only one sand which dies out to the southeast, but very gradually, since it is present as far south as Midland County.

Third zone.—Two chief sands and some others. Both sands die out north and south of Cochran County but both persist to the west. To the east the upper sand dies out before the lower.

Fourth zone.—Two principal sands. Both absent in Cochran County and vicinity. Upper one of the sands is well developed east and west and in Gaines County. The upper is developed in Parmer and Castro counties and to the northwest in New Mexico. The fourth zone is not marked in Midland and Upton counties.

Fifth zone.—Best developed in Gaines, Midland, and central Upton counties.

Sixth zone.—Best developed in the southern part of the basin but extends as far north as Cochran County. Notably deficient in water.

Seventh zone.—This is the Santa Rosa formation. In the area it is found to vary from 100 to 280 feet thick but is remarkably uniform in thickness in most of the wells over this large area as just about 255 feet. It is quite clear that there are four persistent sandstone elements constituting the Santa Rosa of the Triassic basin of west Texas, although there is considerable variation. The highest member I have just found out to be the best stratigraphic marker for structural mapping. The reason for this is that member (D) is only present in the topographic low areas of the pre-Triassic surface, and also the fact that member (A) is the most prolific of all Triassic aquifiers.

There is considerable doubt whether flowing water is obtainable from the Triassic sands. Most of those of the upper, more clayey, divisions outcrop around the western and northwestern margins of the Staked Plains at altitudes in general too low for their waters to flow at the surface in Texas and suffer loss of static head of at least 1 foot per mile in their eastward underground movement. The sandstones and conglomerates of the lower division outcrop in New Mexico at altitudes greater than those of the surface of the Staked Plains in Texas but some of the sands probably do not continue to Texas, and those which do, suffer loss of head in an eastward direction because of friction. The greatest loss of head and of water, however, takes place where these sands are exposed at the surface along Pecos River in New Mexico and along Canadian River at the northern margin of the Staked Plains in Texas. The elevation of the outcrop of these sands in the lower division of the Triassic on the east side of the cap rock in Texas is lower than the surface on top of the plains. The continuity of the sands is broken by faulting in the Canadian Valley of eastern New Mexico and around the solution sinks or "alkali lakes" of the western Staked Plains in Texas and New Mexico. The largest of these sinks are those of the Salt Lakes in the Portales Valley of New Mexico, around Garcia Lake in Deaf Smith County, the Yellowhouse Lakes in Lamb, Hockley, Bailey, and Cochran counties, Cedar Lake in Gaines County, and Shafter Lake in Andrews County, only the larger of these sinks being here noted. However, in much of the Texas area, especially more towards the west, the Triassic water has sufficient head to rise to some extent when the water-bearing sands are reached in drilling.

The quality of the Triassic waters is likewise uncertain. At least in some places the lower Triassic waters contain deleterious mineral constituents derived from the underlying Permian. For instance, the deep wells in Hale County, Texas, report salty water from the Triassic sands. In the vicinity of the "alkali lakes" highly mineralized Permian waters have risen into Triassic, Cretaceous, and Cenozoic horizons, and the "alkali lake" basins are generally encircled by belts of poor or bad water and are underlain by water of even higher mineral content. Some of the waters in the upper division of the Triassic may prove to be usable, especially to the west near the New Mexico line where they have not travelled so far underground and hence have not gathered so much mineral matter as they have in places farther east.

It is found that in general the quality of the water under the Staked Plains becomes poorer with depth. The Cenozoic waters are good except in the vicinity of the "alkali lakes." The Cretaceous waters are usable, except where the Cenozoic waters are poor but are more highly mineralized than those of the Cenozoic. The Triassic waters are more mineralized than are the Cretaceous, and the Permian salt and anhydrite beds waters are probably everywhere so mineralized with common salt, calcium sulphate, and magnesium and potassium compounds as to be totally unfit for irrigation or for animal consumption.

There is very little Cretaceous northeast of a line drawn from the southwest corner of Deaf Smith County southeastward through the town of Lubbock. To the southwest of this line considerable shallow water is obtained from Cretaceous strata. Mr. Roberts reports that the Cretaceous rocks are thickest in eastern Terry County and in most of Lynn County, where the maximum thickness, although it may not occur in any one place, is about 400 feet. His generalized Cretaceous section in Terry and Lynn counties is:

	Thickness *Feet*
Clays with three thin limestone beds	190
Chiefly limestones	70
Red clays, sands, and some gray clays	150

The surface waters in the Upper Cenozoic sands and gravels, which formation does not appear to be more than 400 feet thick anywhere on the Llano Estacado and is generally thinner than 400 feet, are of good quality and are generally obtainable except in the areas of the "alkali lakes" and in places near the eastern escarpment. Larger capacity pumping wells for irrigation have been developed in certain districts in Hale, Floyd, Lamb, Lubbock, and Deaf Smith counties, Texas, and in the Portales Valley of New Mexico.[9]

The water in the Permian "big lime" underneath the salt and anhydrite zone in the Winkler County oil fields is perhaps usable, although high in calcium bicarbonate content.

NORTH PANHANDLE HIGH PLAINS

The North Panhandle High Plains of Texas comprise the territory between Canadian River to the south and New Mexico and Oklahoma on the west, north, and east. In the central area the bed rock strata

[9]Baker, C. L., Geology and underground waters of the northern Llano Estacado: Univ. Texas Bull. 57, 225 pp., 1915.

dip northwards off the Amarillo uplift of southern Moore, northern Potter, and southwestern Hutchinson counties, although there are eastward dips in most of Hutchinson County and westward dips in southwestern Moore and southeastern Hartley counties, on the flanks of the main Amarillo or Panhandle uplift.

Few deep wells have been drilled on the North Panhandle High Plains except in Hutchinson, Moore, and Hartley counties, oil and gas being found in southern Moore and Hutchinson counties on the north flank of the Panhandle or Amarillo uplift. The eastern part of the area is situated in the Anadarko synclinal basin, the trough of which plunges east-southeast and is situated near Canadian River in northern Hemphill County. The bed rock strata dip about 2500 feet east-southeastwards from northeastern Dallam and northern Sherman counties to eastern Hemphill County. The dip is southwards from the Oklahoma border in northeastern Dallam and northern Sherman counties to an area of low structure near the north line of Moore County. In the southwestern area there is an uplift known as the Bravo dome which brings the Permian rocks to the surface along Canadian River in northwestern Oldham County. In western Dallam County the dip is eastwards from the Sierra Grande uplift of Union County, New Mexico.

Borings on the Amarillo uplift and Bravo dome reach the pre-Cambrian crystalline rocks. These are overlain by arkosic sands and gravels reaching up to 250 feet in thickness on the flanks of the uplifts. Overlying the arkose is a formation of limestone with some gray shale interbeds which is probably at least in part Upper Pennsylvanian in age. The top of the cherty phase of this limestone is perhaps the most reliable structural datum plane in the area. Above the cherty limestone is a zone of anhydrite and gray and green shale grading downwards into magnesian limestone. In northeastern Dallam County this zone contains red mudstones and arkoses resembling the Abo formation of New Mexico. Next above is the zone of rock salt, red beds, and anhydrite which attains a thickness of 1200 feet in the trough of the Anadarko basin and is about 1000 feet thick in northern Sherman and northeastern Dallam counties. Several hundred feet of red beds intervene between the base of the salt and the top of the red and green shales. The salt zone is overlain by higher Permian red beds and anhydrite.

The Triassic is present only in the western half of the area and the Cretaceous (including the Morrison formation) is definitely known only in Dallam County. Lower Pliocene sands, clays, and gravels, reaching a maximum known thickness of about 550 feet in Hemphill County, cover the surface of the plains. The maximum known thickness of the Triassic and Cretaceous is about 400 feet. The thickness of the Permian underneath Hemphill County is about 3800 feet. The bed rock floor upon which the upper Pliocene rests slopes east-southeast at the rate of about 14 feet per mile from northeastern Dallam County to Canadian River in eastern Hemphill County.

There is abundant shallow water of good quality in the Cenozoic strata on the plains within the bounding cap rock and in the Cretaceous sandstones of Dallam County. So far as known, the waters in the deeper rocks are highly mineralized except, perhaps, locally in the Triassic strata.

Data concerning ground water conditions in the north Panhandle High Plains are given in the following publications:

Gould, C. N., The geology and water resources of the eastern portion of the Panhandle of Texas: U. S. Geol. Surv., Water-Supply Paper 154, 64 pp., 1906.

———, ———, The geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Surv., Water-Supply Paper 191, 70 pp., 1907.

AREAS OF ARTESIAN FLOW

The principal flowing artesian areas in Texas east of the High Plains include about two-thirds of the Coastal Plain in east and south Texas, the largest artesian area in the state, and small areas near Stoneburg, in Montague County, in the San Saba River valley between Camp San Saba and Voca in McCulloch County, in the Guadalupe River valley around Kerrville, Kerr County, and in the Blanco River valley at Wimberly, Hays County.

There are three general belts of flowing water in the Coastal Plain. The one farthest west is that in which the water occurs principally in the Travis Peak, Glen Rose, and Edwards formations of the Cretaceous. Because in nearly all parts of the Coastal Plain except in northeasternmost Texas, where the dip is south, the Coastal Plain formations dip mainly southeastwards towards the Gulf at a greater rate than the slope of the surface, the water horizons become generally deeper and their waters more highly mineralized in a southeast

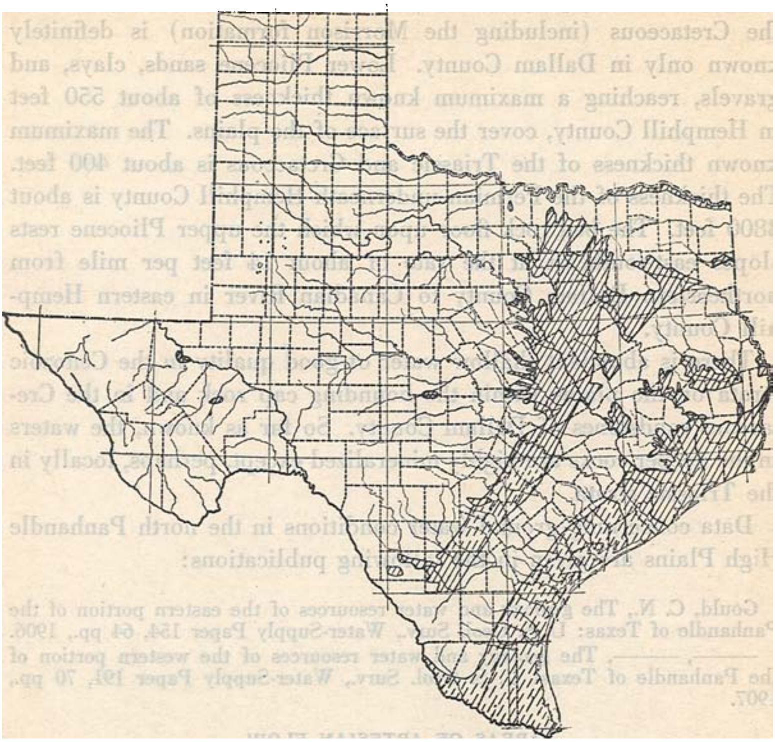

Fig. 23. Sketch map showing the principal known areas where artesian flows have been developed in Texas. Broken lines indicate prospective artesian areas. From University of Texas Bulletin 44, page 125.

direction. The Cretaceous flowing waters are obtainable in the area where the surface rocks are of Upper Cretaceous age and are not too highly mineralized for use except in the east Texas syncline. Farther south the Carrizo and other sands of the Claiborne Eocene afford good waters for considerable distance southeast of their outcrops. Then there comes a belt of later Eocene clays and mineralized sands in which usable waters are relatively scarce. To the southeast, in east Texas, mainly to the east of Brazos River, the sands and sandstones of the Catahoula yield flowing waters of potable quality. Next southeast is a broad belt of Fleming-Lagarto clays, poor in water resources, while closer to the coast are Upper Cenozoic sands and clays with excellent flowing water, which, however, is too highly mineralized to be usable in a relatively narrow belt along the coast itself.

In the Red River drainage basin in northeasternmost Texas the main Cretaceous water horizon, the Woodbine sand, has an outcrop-intake area too low for the water to flow to the surface of higher elevations down dip to the south of the Red River valley.

WATER SUPPLY OF OTHER PARTS OF TEXAS

In the areas of Texas not specifically considered in the preceding, more detailed information is in general available. The publications on the subject are listed below. The earlier ones are now out of print but can be found in most of the larger libraries.

Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Surv., Water-Supply Paper 335, 365 pp., 1914. Relates to the following counties: Anderson, Angelina, Brazoria, Brazos, Burleson, Chambers, Cherokee, Falls, Fort Bend, Freestone, Galveston, Gregg, Grimes, Hardin, Harris, Harrison, Henderson, Houston, Jasper, Jefferson, Kaufman, Leon, Liberty, Limestone, Madison, Marion, Montgomery, Milam, Nacogdoches, Navarro, Newton, Orange, Panola, Polk, Robertson, Rusk, Sabine, San Augustine, San Jacinto, Shelby, Smith, Trinity, Tyler, Upshur, Van Zandt, Walker, Waller, and Wood.

Deussen, Alexander, and Dole, R. B., Ground-water in La Salle and McMullen counties, Texas: U. S. Geol. Surv., Water-Supply Paper 375, pp. 141–177, 1916.

Gordon, C. H., Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Surv., Water-Supply Paper 317, 88 pp., 1913. Relates to the following counties: Archer, Baylor, Clay, Foard, Hardeman, Haskell, Jack, Knox, Montague, Throckmorton. Young, Wichita, and Wilbarger.

———, ———, Geology and underground waters of northeastern Texas: U. S. Geol. Surv., Water-Supply Paper 276, 78 pp., 1911. Relates to the following counties: Bowie, Camp, Cass, Delta, Franklin, Hopkins, Lamar, Morris, Red River, and Titus.

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METALLIC AND NON-METALLIC MINERALS AND ORES

CHARLES LAURENCE BAKER

INCLUDING CHAPTERS ON IRON ORES, BY EDWIN B. ECKEL AND PAUL E. M. PURCELL, AND ON SILVER AND MERCURY ORES, BY CLYDE P. ROSS AND W. E. CARTWRIGHT

ARSENIC MINERALS AND ORES

Arsenopyrite, the principal arsenic mineral for commercial purposes, is a silvery-white or steel-gray mineral. It is a sulpharsenide of iron, FeAsS or $FeS_2.FeAS_2$ with 46 per cent arsenic, 19.7 per cent sulphur, and 34.3 per cent iron. This mineral is also known as mispickel or arsenical pyrites. It was the discovery of arsenopyrite on the north side of Honey Creek cove in Llano County by Don Bernardo de Miranda and associates in 1756 which gave origin to the legend of the lost San Saba silver mine, still believed by the credulous. The color of arsenopyrite somewhat closely resembles that of fresh-minted silver, but metallic silver is malleable while arsenopyrite is brittle.

Ordinary commercial or white arsenic (arsenious oxide) is produced largely as a by-product from flue dust and fumes in smelters. Most arsenical alloys, such as hard lead and several varieties of speculum metal, are brittle. Various arsenic salts are used in medicines, and a number of compounds are used in many poisons, such as insecticides, weed killers, and cattle and sheep dips. Considerable calcium arsenate is used for dusting cotton plants in order to check the ravages of the boll weevil. Some additional uses for arsenic are as an alloy in lead for bullets and shot (hard lead); in fireworks and boiler compounds; as a hair-removing agent; to prevent the ravages of insects in stuffed animals, wall paper, and book bindings; in the manufacture of paint pigments, opal glass, and enamels; in textile dyeing and calico printing; and as a bronzing and decoloring agent for glass. It is remarkable that arsenic is found in some 130 different minerals, or about 12 per cent of the 1100 mineral species known.

The Honey Creek cove deposits in Llano County appear to be localized along the Honey Creek fault zone in the area where there occurs the maximum displacement of about 1800 feet. The old workings, known as the Boyd shaft, are on the Bedford tract about a mile north of the creek. The later workings are on the Roberts tract, south of the creek. The writer found arsenopyrite disseminated in hornblende schists in the bed of Honey Creek between the molybdenite prospect and the Llano-Round Mountain road crossing. A deposit of arsenopyrite has been prospected recently at the west base of the Franklin Mountains, east of Canutillo, El Paso County.

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BARIUM MINERALS AND ORES

Barite, known also as barytes or heavy spar, is barium sulphate. It crystallizes in the orthorhombic system, usually in tabular prismatic forms, often lamellar or platy, cleaving into thin, parallel, but brittle sheets. It is also found often in globular, columnar, fibrous or lamellar, concretionary, stalactitic, crested, nodular, radial or botryoidal or mammillary forms. When granular, it has the appearance of marble. It is soft, being easily scratched with a knife (its hardness is 2.5–3.5). It is remarkably heavy, with a specific gravity of 4.3–4.9. Its streak is white. The color of the mineral is white, yellow, gray, blue, red, or brown. When heated, it colors the flame yellowish green. It is insoluble in acids and when coarsely crystalline has a vitreous to almost resinous or pearly lustre.

Barite occurs commonly in connection with beds or veins of metallic ores, more especially of lead but also copper, silver, cobalt, manganese, and antimony. It is found more or less disseminated in beds of limestone and sandstone and as somewhat earthy or solid masses in marls and shales. Much of that produced is in nodular masses in clay. In fact, it may be found in any rock, especially as a filling of cavities. It is sometimes deposited from waters carrying barium salts in solution. In the Saratoga oil field, Hardin County, Texas, it is deposited as spherical, buckshot-like concretions inside the screens in the oil wells. In the Hockley salt dome, Harris County, Texas, it is found as numerous concretionary masses of radiating columnar structure in a bed of blue-gray clay about 6 feet thick, lying directly upon the cap rock. Since barite is both heavy and relatively insoluble, it is left behind when the other constituents of the rocks are either dissolved out or washed away. Deposits now being mined in Missouri and Georgia appear to be mainly residual concentrations, resulting from surface weathering of deposits disseminated in sedimentary rocks.

The largest amount of barite is used in the manufacture of lithopone. Lithopone is an artificially prepared compound composed of 70 per cent barium sulphate and 30 per cent zinc sulphate, precipitated together. It is a standard pigment and filler, the increasing use of which is gradually causing a decrease in the consumption of lead pigments. Over 200,000 tons of lithopone were produced in 1929. Three-fourths of it is used in paints, varnishes, and lacquers, over one-sixth in floor coverings and textiles, about 3 per cent in rubber and 5 per cent in other industries. The use of lithopone is increasing rapidly.

Barium sulphate precipitated (blanc-fixe) is used largely in rubber manufactures. It is used also for interior painting of battleships and on all steel interiors of seagoing vessels and in taking interior X-ray pictures of the human body.

Nearly $2,500,000 worth of barium chemicals was consumed in 1929. These chemicals are chiefly barium carbonate and barium chloride. Barium carbonate is used by pressed brick and rubber manufacturers to neutralize the sulphur content. Barium chloride is used as a mordant by dye-color manufacturers, in the tanning of leather, and in the manufacture of battery plates. Barium binoxide is used in the distillation of peroxide of hydrogen. Barium nitrate is used in the munitions industry and in making "red fire" material.

Ground barytes is used mainly as an inert mineral filler in paper, rubber, cloth, linoleum, and oilcloth, and as a paint pigment and inert extender. It is especially useful as a filler and a surfacing material for playing cards, enamelled paper, and oilcloth, in which a highly calendered surface is desired. It is used also as a filler in making artificial ivory and buttons; as a base for the precipitation of lake colors; in pottery and other ceramic glazes and enamels; as a constituent of some types of glass; and as an inert filler and body material for many products where a heavy, crystalline filler is desired.

Increasing amounts of crude ground barite are being used to make heavy drilling mud to overcome gas pressures in drilling wells.

Numerous other uses are found for barites. J. P. D. Hull[1] gives the following tabulation of uses of this mineral.

I. Ground barytes
   1. Base, body, substance, load, dressing, filler in white mixed paints, colored pigments, rubber, rope, putty, fabrics, paper, cardboard, wood preservatives, imitation marble, white figures, jasper ware, asphalt, pavement surfacing.
   2. Enamel for paper, cardboard, metal work, porcelain, pottery.
   3. Adulterant in powdered sugar, candy, flour, Paris green, fertilizer.

II. Lithopone
   1. Pigment in "flat" wall paints.
   2. Filler in oilcloth, linoleum, fabrics, rubber, soap, calcimine.
   3. Enamel for oilcloth, linoleum, paper collars, playing cards, bristol board.

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[1]Hull, J. P. D, Report on the barytes deposits of Georgia: Georgia Geol. Surv., Bull. 36, pp. 5-6, 1920.

III. Barium chemicals
1. Barium binoxide or peroxide (BaO_2) in preparation of hydrogen peroxide and oxygen.
2. Barium hydroxide as chemical agent.
3. Barium monoxide in preparation of the binoxide and hydroxide and manufacture of special glasses.
4. Barium carbonate in manufacture of cyanides, lithopone, bricks, barium chemicals, green fire, luster in glass, rat poisons, water softener, flat wall paints, ceramic and rubber industries, case carbonizing steel.
5. Barium chloride in lithopone, blanc-fixe, barium salts, water softener, chemical reagent, purification of table salt, ceramic arts, rat poison.
6. Barium chlorate in pyrotechnics.
7. Barium nitrate in green fire, signal lights, explosive "saxi-fragin."
8. Barium sulphate (blanc-fixe or permanent white) in paint industry, glazed paper, putty, fabrication of rubber and of lake colors, glass making, manufacture of alumina from bauxite, stiffening and printing calicos, air- and germ-proofing canvas casings for meat.
9. Barium hydrate in lithopone, blanc-fixe, clarifying sugar and recovering sugar from molasses, purifying and softening water, glass making, preparing hides for tannins, mercerizing cotton goods, reducing agent in aniline industry.
10. Barium sulphide in lithopone, blanc-fixe, barium compounds, depilatory, insecticide, luminous paint.
11. Barium carbide in fixation of atmospheric nitrogen.

New uses are in barium aluminate in a patented process for purifying water from soluble sulphates and in glass and enamel making.

Barite is found widely distributed, but its value is not great enough to encourage its development except in highly industrialized countries. Germany is the leading producer, the United States being second. Great Britain, France, Italy, and Belgium are the other leading producers. In 1929 the United States produced 277,269 short tons, valued at the mines at $1,850,706 or $6.67 per ton. Crude barite imported into the United States in 1929 amounted to 85,729 tons with an average value per ton of $3.32. This was the largest amount ever imported in one year. Most of the imports came from Germany. Besides crude barite, the United States imported also $1,168,760 worth of barium compounds in 1929. The United States exported $463,235 worth of lithopone in 1929, at an average price per ton of $101.68.

Most of the barite produced in the United States comes from Missouri and Georgia. Practically all the Georgia product is mined by steam shovel from hard crystalline residual nodules in clay in the Cartersville district in Bartow County. Missouri now produces more than Georgia. Most of the Missouri ore is soft, occurring in small, scattered residual deposits, mostly worked by hand, and used largely for ground barytes. Before 1915, Missouri produced about 65 per cent of the United States total. For some years after 1915 Georgia produced about half of the United States total. Other producing states are Tennessee, California, Colorado, Nevada, South Carolina, Virginia, and Wisconsin. Alabama, Alaska, Kentucky, Virginia, Maryland, North Carolina, Montana, New Mexico, Idaho, Utah, Illinois, and Texas also have barite deposits.

Most of the market is in the Philadelphia and St. Louis manufacturing districts, although there are chemical plants in Tennessee and West Virginia, ground barytes plants in Georgia, Kentucky, Virginia, and South Carolina and a lithopone plant in Maryland. Ground barytes, lithopone, and barium chemicals are manufactured in California also. Barite is ground in Georgia. It is used in the manufacture of chemicals in Colorado. James M. Hill[2] gives the following brief description of the preparation of those three classes of barium products.

The treatment of crude barytes to make ground barytes varies in different plants. The general practice, however, seems to be to crush to about 1 inch and log-wash and jig to remove clay, calcite, flourite, silica, and part of the iron oxide. This cleaned material is next crushed to one-fourth to one-eighth inch at some plants and at others ground fine and subjected to a bleaching process. The bleaching, largely to remove iron oxide, is accomplished by treating the material with sulphuric acid from 8 to 12 hours in lead-lined wooden tanks. The bleached product is washed several times and ground in burr mills or pulverizers to pass 200 to 300 mesh, and in some plants is water-floated to insure a uniformly fine product, and is then dried, pulverized, and packed. Much care is required not only in the bleaching but also in the drying operation to insure a uniformly perfect color. . . .

Lithopone is a mixture of approximately 70 per cent barium sulphate, 25 to 29 per cent zinc sulphide, and 1 to 5 per cent zinc oxide, which is made by mixing hot solutions of barium sulphide and zinc sulphate. In the preparation of high-grade lithopone the solutions of barium and zinc compounds must be essentially pure. The precipitate from the tanks is filter-pressed, dried, subjected to considerable heat, quenched in water, ground to pulp, filter-pressed, dried and packed for shipment. . . .

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[2]Hill, J. M., Barytes and strontium: U. S. Geol. Surv., Mineral Resources of the United States, 1915, Part II, Nonmetals, pp. 181–183, 1917.

The principal barium chemicals made in the United States are the binoxide, carbonate, chloride, hydroxide, nitrate and sulphate or blanc-fixe. . . .

The manufacturers of barium chemicals prefer to use washed high-grade barytes of the soft variety; nevertheless they can, and some do, use barytes which could not be used for the highest grades of ground floated barytes. The first step in the barium chemical plants is the reduction of the barium sulphate to the sulphide, which is soluble in water. The barytes is finely crushed and mixed with a certain proportion of pulverized coal and common salt. The mix varies in different plants, but is generally stated to be about one-fourth coal by volume. This material is fed to rotating furnaces, where it is roasted from three to four hours. The charge is next leached in most plants, first, with a boiling, weak solution of barium sulphide, which is obtained by washing the leached material with hot water. The ash, after the leaching and washing, is waste, though it may contain some undissolved barium compounds. The extraction of barium sulphide is ordinarily stated to be 70 per cent, though it is known that a higher extraction can be made. The liquid from the barium sulphide leach is stored in large heated tanks, from which it is drawn into the different vats for the preparation of the various salts. Barium sulphide can be precipitated by allowing the solution to cool below 150°.

Since 1924 considerable mining has been done in Missouri with gasoline, steam, or electric shovels and power haulage. Much of the Missouri ore is still cleaned by hand, after thorough drying. Small portable jigs and log washers are coming into use. Milling practice varies in Missouri but in general is about as follows:[3]

The ore first passes over a grizzly, from which the large boulders and roots are removed by hand. From the grizzly the undersize goes to log washers from which the clay is discharged to a sledge pond. The ore and rock are then crushed and delivered to jigs that make three products, a tailing discharged to the waste pile, a concentrate ready for market, and a middling that is further treated on tables.

Occurrences in Texas.—Barite, associated with psilomelane (hydrous manganese manganate) and a small amount of hematite, occurs in the Walter Mayfield prospect, about 5 miles west and a little south of Chispa section house on the Southern Pacific Railroad, in western Jeff Davis County, Texas. It is found in a fissure vein along a fault, the vein gangue being finely crystalline quartz or chalcedony. The foot wall, which forms the dividing ridge between the drainages of Van Horn and Chispa creeks, is composed of Georgetown Cretaceous limestone. The hanging wall is buried beneath the

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[3]Dake, C. L. The geology of the Potosi and Edgehill quadrangles: Missouri Bur. Geology and Mines vol. 23, 2nd ser., p. 209, 1930.

alluvium of the Chispa Creek flat. There has not been sufficient prospecting to determine the value of the deposit.

Barite is one of the gangue minerals of the silver-copper vein at the Hazel mine, near the Culberson-Hudspeth county line, 10 miles north-northwest of Van Horn.

Barite in nodules with radiating columnar structure occurs near the base of the Rough Creek shale member of the Tesnus formation of Carboniferous age at Peña Blanca Spring, on the old Lockhausen ranch, 9½ miles east-southeast of Marathon in Brewster County.

Dr. J. A. Udden found a vein of barite 5 or 6 feet wide in the Lower Cretaceous limestone east of Maravillas Creek and some distance east, northeast, or southeast of Dog Canyon in Brewster County.

Barite has been reported from Taylor, Gillespie, and Uvalde counties. It occurs with quartz in a vein varying from 22 to 40 inches wide in the pre-Cambrian schists in northeastern Gillespie County. It occurs as a bed associated with epidote schists on the Freeman farm northwest of Babyhead, Llano County. Concretionary nodules of radiating prismatic barite have been found recently 10 miles southwest of the town of San Saba in San Saba County. Concretionary nodules occur in the Taylor marls of the Upper Cretaceous in Presidio County and in Travis, Navarro, and other counties in central Texas.

At present no barite is being produced in Texas. It is, however, in demand for use in preparing drilling muds.

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COPPER MINERALS AND ORES

Although ores of copper are widespread in Texas, the total production of the metal has been only 1,307,960 pounds, valued at $211,381. The Hazel mine, 10 miles north of Van Horn, in Culberson County, has produced most of the copper, the greater part of the remainder having come from neighboring prospects in the Carrizo Mountains. These copper ores are silver-bearing. Since they occur in shear and fault zones in pre-Cambrian rocks, the age of the ores is uncertain.

Copper, silver, and zinc ores of Tertiary age in the Quitman Mountains have been described briefly in the section on zinc. Pre-Cambrian copper ores, in places carrying silver, are known in the metamorphic and both acidic and basic intrusive rocks of the Llano uplift in Llano, Mason, Burnet, Gillespie, and Blanco counties. Copper oxides, sulphides, and carbonates, replacements usually of originally carbonaceous matter, are widespread in the Permian red beds of north-central Texas. The copper sulphide, chalcopyrite, is fairly common in the proximity of the salt domes of the Gulf Coastal Plain.

Carrizo Mountains, Culberson and Hudspeth counties.—The Hazel mine near the Culberson-Hudspeth county boundary at the south foot of the Sierra Diablo was worked for eight or ten years subsequently to 1885 and was again worked for a period beginning in 1912. From 1926 to 1928 about 12,500 tons of low-grade ore, averaging 9 ounces silver to the ton and 0.42 per cent copper, were shipped from the old dumps. In 1929 shipments from new underground development totalled 4810 tons of highly siliceous (66 per cent SiO_2) oxidized ore carrying 7.63 ounces silver to the ton and 1.53 per cent copper. Shipments of newly-mined ore continued during the first seven months of 1929, and a 100-ton flotation mill treated from May 1 to October 1, 1930, a total of 4616 tons of ore yielding 238 tons of copper-silver concentrates carrying 23,260 ounces of silver and 102,587 pounds of copper. It seems likely that the total value of the Hazel mine production has been less than $2,000,000.

Von Streeruwitz, describing the Hazel mine in 1892, states that it was worked from two shafts, 575 and 375 feet deep, situated 1800 feet apart, from which there were numerous cross-cuts. Richardson[4] describes the deposit as follows:

> Recent development shows that mineralization has taken place in a zone of small faults between the larger displacements at the southern end of the Sierra Diablo. Surface strippings show three mineralized belts striking from N. 65° E. to N. 85° E., each consisting of a band of country rock, the fine-grained

[4]Richardson, G. B., Description of the Van Horn quadrangle: U. S. Geol. Surv., Geol. Atlas, Van Horn folio (No. 194), 9 pp., 1914.

sandstone of the Millican formation, from 3 to 6 feet wide, which has been bleached to a buff or creamy tint. This decolorized sandstone, standing almost vertical, carries the main veins which swell and pitch irregularly, the greatest thickness reported by the engineer in charge being 18 inches. In one place the main vein, there 2 to 4 inches thick, practically vertical, is bounded on one side by slickensided fault surface and branches on the other side into many minute interlacing veinlets, the whole constituting a mineralized zone 3 to 5 feet thick. The most important minerals noted were chalcopyrite, tetrahedrite, malachite, and azurite in a gangue consisting largely of barite and calcite.

There are a number of prospects in the Millican and Carrizo Mountain formations of the pre-Cambrian, rather widespread throughout the Carrizo and northern Eagle Mountains, in which ores occur in small veins, or irregularly disseminated, or in fault zones. Copper arsenate associated with turquoise, is found at the old Maltby prospect, 6 miles west of Van Horn. The Don Quixote and Sancho Panza prospect shipped during the late eighties and early nineties $10,000 worth of high-grade lead-silver ores, occurring in pockets within 20 feet of the surface. Other small shippers have been the Pecos group of claims, the Black Shaft, the Mohawk, the Roundtree, the St. Elmo, the Little Lightning, and the Copper Queen prospects.

Other Trans-Pecos copper prospects.—Copper carbonates occur in fissure veins in the Capitan limestone of Permian age near the summit of the Guadalupe Mountains between 1 and 2 miles south of the New Mexico state line. The Plata Verde prospect north of the Mica Mine at the west foot of the northern Van Horn Mountains exhibits malachite with some azurite in a slickensided plane of movement following approximately the bedding planes of Permian sandstone, shale, and limestone. The copper carbonates, stated to carry some silver, are irregularly disseminated through the sandstones. The associated limetones have cavern fillings of black iron and manganese oxides. One mile southwest of Sierra Blanca, contact metamorphic copper deposits occur at the junction of three intrusive sills with Cretaceous limestone. Garnet and amorphous hematite with some specularite occur on the contact. The ore minerals are copper carbonates filling cracks and forming thin seams and stringers in the metamorphosed limestone. Both hematite and copper carbonates form a cement for breccias. Chalcedonization was a late phase, and there are some botryoidal, mammillary, and radiating thin coatings of chrysocolla. Shipments of ore carrying 18 per cent copper were made from the John Gilcrease claims, northwest side of the Quitman Mountains. There are some copper prospects, showing mainly carbonates, in the Solitario of the Brewster-Presidio county boundary.

Llano uplift, central Texas.—The copper sulphides and carbonates occurring in a number of places in the central Texas pre-Cambrian rocks afford little promise of successful development. The copper sulphides disseminated in the basic igneous rocks of southeastern Llano and northeastern Gillespie counties, although apparently never prospected, have an apparent uniformity in copper content and sufficient percentage of metal to warrant thorough exploration provided copper ever again attains its old time values. A number of these more or less altered but still very hard and tough basic intrusives cross the Llano-Round Mountain road south of Sandy Creek, and others may be found in that general vicinity.

Permian red beds of north-central Texas.—Most of the copper of the Texas Permian red beds occurs in Archer, Baylor, Foard, Hardeman, Haskell, Jones, King, Knox, and Stonewall counties. A few small shipments have been made, but the ores have not proved to be profitable. Rich pockets of chalcocite occur in clays, and there are in places nodules and concretions of black copper oxides, but most of the ore occurs as pseudomorphs after fossil wood. The carbonates, malachite and azurite, are the most abundant copper minerals. Chalcocite is the primary ore.

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FELDSPAR

The feldspars are silicates of the alkali and alkaline earth metals. They are classified generally under the systems in which they crystallize, as the monoclinic orthoclase, soda-orthoclase, hyalophane, and celsian, the triclinic microcline, anorthoclase, albite, and anorthite. Intermediate between the last two are the isomorphous sub-species oligoclase, andesine, labradorite, and bytownite.

In Texas the most important commercial feldspars are probably orthoclase (potassium aluminum silicate) and microcline (of the same composition as orthoclase) and, subordinately, albite (sodium aluminum silicate). Orthoclase and microcline in crystals varying up to more than a foot in major dimension occur as the most abundant constituent of pegmatite dikes in the pre-Cambrian rocks of Llano, Mason, Burnet, Gillespie, and Blanco counties of the Llano uplift and in the Van Horn uplift of the southern border area of Hudspeth and Culberson counties. The best known examples are Baringer Hill, Llano County, the minerals of which are described in the section on rare-earth minerals, and the Mica Mine of the Van Horn uplift, noted also in the section on mica. Coarse-grained and porphyritic granites, most of which are "pink," contain abundant potash feldspars, some of the granites of the Llano uplift having feldspar crystals 2 inches long. Most of the coarse-grained granites of Trans-Pecos Texas occur in the Quitman and Franklin mountains and the Diablo Plateau in El Paso and Hudspeth counties.

It has proven expensive and difficult to separate feldspar from quartz, biotite, and other minerals, and, therefore, hand cobbing has usually been done, but lately some progress appears to have been made towards cheap and efficient mechanical separation. Biotite contains iron and, therefore, must be removed from either feldspar or quartz, most of the commercial uses of which depend on their freedom from iron. This is accomplished by fine grinding, tabling, and washing, the tailing of mica being salable.[5] The small amount of remaining mica, with small amounts of feldspar and quartz, is then removed by flotation, by the use of sufficiently small quantities of flotation reagents. Oleates are used as collecting agents in the final process of separating feldspar from quartz in biotite granite.[6]

The Llano uplift of central Texas contains vast quantities of disintegrated granite and pegmatite dikes, which require no mining or quarrying and can be handled by dragline, scraper, or shovel, and ground very cheaply. Unfortunately, however, ground feldspar now sells for around $11 per ton (crude feldspar for about $5 per ton) which is less than the freight rate from Texas to the centers of consumption. Therein exists another excellent reason why Texas, with the world's greatest known supply of natural gas for fuel, should be a manufacturer of ceramic products.

Nearly seven-eighths of the feldspar produced in the United States is used as a flux in the production of glass, pottery, enamel and sanitary ware, brick, and tile. It melts without becoming entirely fluid and upon recooling becomes a strong, colorless or only slightly colored glass. In most pottery it is a part of both body and glaze, and its cheapness of late has enabled it to a considerable extent to supplant clays and other crude materials. Feldspar is one of the essential ingredients in opalescent glass. It is used in dentistry for artificial teeth and porcelain inlays. Enamel for bath tubs, wash bowls, and other purposes contains considerable feldspar. It is one of the principal ingredients in electrical insulators. Other uses are for scouring soaps and window cleaning compounds, as binder for abrasive wheels, as a surfacing for prepared roofing, as a coating for stucco and concrete, as sand-blast, for poultry grit, foundry facings, floor covering, sandpaper, paint and wood filler, in terra cotta, and as a flue-dust arrester.

The 1932 production of crude feldspar in the United States was 104,715 long tons, valued at $539,641 and of ground feldspar was 104,715 long tons, valued at $1,174,833. Over half was produced in North Carolina, with New Hampshire and Maine taking second

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[5] Henry, S. T., Eng. and Min. Jour., vol. 127, p. 630, 1929.

[6] Iverson, H. G., Separation of feldspar from quartz: Eng. and Min. Jour., vol. 133, pp. 227–229, 1932.

and third places. In the west, South Dakota, Colorado, Nevada, Arizona, and California produce some feldspar.

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Bowles, Oliver, Feldspar: U. S. Bur. Mines, Inf. Circ. 6381, 21 pp., including a bibliography, 1930.

GOLD

The total value of gold produced to date in the state of Texas is probably about $125,000. The production has come as a by-product of silver and copper ores mined in Trans-Pecos Texas and in a small amount from the Heath mine in Llano County.

Anyone contemplating prospecting in Texas for any mineral resource whatever should know that all mineral rights belong to owners of the land surface and that there is no Federal public land which can be acquired gratis by the discoverer of a mineral deposit. Without exception royalties must be paid by the operator, either to private owners or to the state, unless he owns the land in fee.

The regions in Texas that have yielded small amounts of gold are as follows: the Llano uplift, Trans-Pecos Texas, and the Edwards Plateau. In other parts of Texas, so far as can now be judged, gold can scarcely be expected to occur in profitable amounts. A small quantity of placer gold has been found in some of the Eocene sandstones of the Gulf Coastal Plain but not in profitable amounts.

Llano uplift of central Texas.—In the Llano uplift gold in the consolidated bed rocks is confined to quartz veinlets and stringers in the metamorphic schists, quartzites, phyllites, slates, and marbles. These rocks are confined to Mason and Llano counties, a narrow strip along the eastern two-thirds of the north line of Gillespie County and a small area in the center of the west part of Burnet County. Even within the area so given half of the surface is occupied by outcrops of barren granite and sedimentary rocks of later date of formation than the metamorphics. Consequently there is not more than 1000 square miles of area of rocks which might contain any appreciable amount of gold.

Outcrops in the metamorphic area are, moreover, relatively scarce. Most of the surface is covered either by stream-transported gravels, sands, and clays or by residual soils formed by the decomposition of the bed rocks. The amount of outcrop is constantly decreasing because cultivation and over-grazing of the country have led to the growth of a scrub jungle vegetation difficult to penetrate and to choking of the water courses with débris. Both processes have buried much of the formerly outcropping rock.

There are many fairly wide and extensive veins of milky-white quartz in both the metamorphic rocks and the granites, but, so far as known, these do not contain gold or other useful minerals. Pegmatite or graphic granite, aplite, and spar (feldspar) veins are likewise common and carry some of the following minerals: quartz, microcline or orthoclase feldspar, mica (biotite or muscovite), fluorite, beryl, tourmaline, topaz, molybdenite, rare earth minerals, cassiterite, and other minerals. None of these are known to carry any profitable amount of gold. Appreciable amounts of gold so far found appear to be confined to quartz stringers or veinlets which in some, perhaps most, instances probably are merely the "rootlets" of veins which once may have existed in volumes sufficient to be profitable but have been eroded away in the course of time. Gold occurs in these deposits either in the free state or combined with pyrite. Zones of contact between the metamorphics and the granite in places contain bands of pyrite, and such bands are sometimes found in slates and other metamorphic rocks at distances considerably removed from granite contacts, but such of these pyritic bands as have been assayed do not show even a trace of gold.

Erosion of gullies and larger water courses, floods, landslides, and grass and brush fires constantly expose new bed rock outcrops to the view, and it is always within the range of possibility that one or more such processes may bring to light a vein of sufficient size and mineral content to be profitable. Also, for reasons already given, it is apparent to those sufficiently well informed that neither this nor any other possibly mineral-bearing area of Texas has ever been adequately prospected. Consequently, it is foolhardy either to condemn the area or to look on it with any great amount of favor.

The study of the problem of whether profitable placer deposits, derived from the wearing away and subsequent concentration of gold from formerly existing veins, exist in this area requires the consideration of a long and complex geologic history. The gold-bearing veins were formed either during the time when various original ordinary sedimentary rocks—shales, sandstones, and limestones—were changed (metamorphosed) by heat and pressure into the schists, slates, phyllites, quartzites, and marbles, or after the already metamorphosed rocks were intruded by the then molten granite or other intrusive rocks. After the mineralization, an immense amount of erosion uncovered the surface to the once deeply buried granite and metamorphic rocks. Whatever placer gold was derived from the wasting away of the veins during this truly tremendous erosion remained in part in the residual soils and drainage courses of the area or was transported mainly by stream water to places outside of it.

When the Upper Cambrian sea finally covered the area and deposited the Hickory sandstone and conglomerate, whatever free detrital or residual gold was present was reconcentrated in the basal conglomerate and sandstone beds. In certain localities in these it may exist in profitable quantities and would be expected to occur in the basal Hickory formation, most likely along old drainage courses, valleys, or channels which were present in the surface of the metamorphic rocks when the basal conglomerates and sandstones were deposited. Long after the formation of these beds the area was faulted, and there are now numerous fault blocks of the Hickory and overlying sedimentary rocks which have been down dropped and in which the Hickory formation lies at lower levels than do the outcropping metamorphics in adjacent, relatively uplifted blocks. The prospector must be able to discriminate clearly between such blocks lowered by faulting and the original channels and valleys formed long previous to the faulting. Such channels and valleys may be found in the down-faulted as well as the up-faulted blocks, but it will not do to make the error of confusing a block lowered by faulting with one of the ancient channels or valleys in which the gold is liable to have been concentrated by stream and wave wash.

It was during this first epoch of great erosion that conditions for concentrating placer gold were more favorable, first, because a greater amount of erosion was accomplished and, second, because it was probably then that most of the gold-bearing veins were worn away. There have been, however, in the Llano uplift two other and later long periods of erosion of the crystalline rocks during which gold may have been concentrated in placer deposits.

One of these was during the very long time which elapsed between the Pennsylvanian and Cretaceous periods. Whatever gold was freed from the veins and rocks during this time was reconcentrated in the basal sands and gravels of Cretaceous age under the same conditions as already set forth. However, there was relatively little faulting after the deposition of the Cretaceous rocks. The outcrops of Cretaceous form on all sides the bounding rim of the lower central basin of older rocks, and within the basin there is one important outlier which forms the long narrow ridge in northern Mason County known as the Mason Mountains. The rim rock of the Cretaceous is particularly prominent and nearest the uplift on its south and east sides. The basal gravels and sands of the Cretaceous, especially when these fill old valleys and channels in the underlying rocks, are possibly in places gold-bearing in quantities sufficient to be profitable.

Much later the covering of Cretaceous rocks was worn away from the heart of the area and the older rocks, as we see them today, were exposed once more. The drainage lines which uncovered the ancient rocks were all part of the Colorado River system, and the river, as the master stream of the area, controlled their action. The down-cutting of Colorado River and its tributaries has been slowed down at many times and in many places by hard belts or layers of rock. There are similar obstructions along the various tributaries of the Colorado. The two tributaries of Colorado River which drain sizable areas from which gold may be derived are Llano River and Sandy Creek. There is probably little gold in the valley of Colorado River above the mouth of Llano River at Kingsland, because the river basin above there does not cross any considerable areas which contain gold. Accordingly, the search for placer in present valleys is practically restricted to the valley of the Colorado below Kingsland and the drainage basins of Llano River to the east of the west line of Mason County and of Sandy Creek.

Sandy Creek has a drainage basin of 385 square miles. This includes large areas of the metamorphics most favorable for gold as well as the widest variety of different types of intrusive igneous rocks in the whole Llano uplift. Moreover, this basin has exhibited the most extensive and notable gold showings in central Texas.

The upper basin of Sandy Creek is held at a high level by the hard rocks through which the stream flows between Riley and Cedar mountains, in the stretch between Potato Hill and Click Gap. It is along the gorge in this part of the stream's course that the coarser particles of gold, eroded and transported from the upper basin, are apt to have been caught in depressions in the solid rock at the base of the loose wash deposits brought down by the creek. Just south of the Llano-Gillespie county line a narrows in the course of Cole Creek is formed by a serpentine outcrop. The bed rock of the creek bed in this narrows is an excellent place for gold to accumulate, although serpentine bed rock is usually very difficult territory from which to recover placer gold. There is another narrows near the mouth of Sandy Creek.

Above all three narrows noted there are extensive areas of flattish land in the creek basins over which the stream channels have wandered in former times. The divide ridges on these flats are covered with stream-transported sand and gravel. The present major stream courses have cut in places as much as 200 feet below these old valley flats. Much of the placer gold is probably scattered over these valley flats in quantities too small to be profitable, but in certain localities there may be enough gold to be profitable. Such places, if they exist, will be where there once was drainage from a sufficiently rich localized source of gold.

In the time since the old valley flats were formed their areas have been pretty thoroughly dissected by renewal of the down-cutting and erosive power of the present drainage. Considerable reconcentration of gold has taken place in the minor tributaries as well as in the main creeks during this drainage intrenchment or dissection.

The lower courses of Crabapple and Cole creeks, the two principal tributaries, and of the main Sandy Creek itself below Enchanted Rock, carry large amounts of water, much of which is underflow through the sands and gravel. It is precisely these places where most of the unconsolidated placer gold will be found if it exists at all. But the lone prospector, without considerable capital, cannot even prospect these places, let alone work the possible gold-bearing gravels and sands. In order to prospect these stream courses it is necessary to dig a large number of holes down to the bed rock with auger or other types of placer prospecting drills, or, if shafts are sunk, to shut off the water with caissons. Such prospecting is expensive, and if and when such may demonstrate the presence of gold in profitable quantity, the only way in which it can be recovered is with a dredge which is able to dig itself up or down the stream course. It may also turn out that prospecting will show sufficient gold but it may be for the most part in such small particles ("flour gold") that no profit can be made.

The courses of Llano River and its tributaries can be prospected properly only as set forth in the preceding paragraph, the conditions being similar to those of the Sandy Creek basin.

Trans-Pecos Texas.—There is a considerable area in the vicinity of the town of Van Horn and of Lobo railroad station in which there are large outcrops of metamorphic rocks of the same age and nature as those of the Llano uplift and to which the remarks made already apply in large part. This territory includes the Carrizo Mountains, the southeastern flanks of the Diablo Plateau (Sierra Diablo), the lower part of the western escarpment of the Wylie Mountains, and a small area northeast of Eagle Mountain.

In most of the rest of the mountainous part of Trans-Pecos Texas mineralization has been much later, indeed as late as the time of the last uncovering of the most ancient rocks of the Llano uplift. In these mountains there are numerous areas where intrusions of suitable kinds of igneous rocks have taken place in country rocks also suitable for deposition of gold and other metallic minerals. But up to the present no profitable gold deposits have been discovered, and the sum total of profitable metal mines includes only the silver mine at Shafter and the few quicksilver mines of the Terlingua district. Nevertheless, the territory cannot be condemned wholly because of the poor showing it has made. It certainly has not been properly or adequately prospected.

Edwards Plateau.—In the Edwards Plateau region there does not appear to be any great promise of profitable gold mining. Some of the intrusive igneous rocks of Uvalde and Kinney counties have a favorable composition, but they intrude not very favorable "country" rocks, which are mainly limestone or marls. Very small and entirely unworkable values of gold and silver have been assayed from veins of iron carbonate and oxide in Uvalde County. From Williamson County, 20 miles north of Georgetown, some samples of decomposed limestone heavily stained with oxide of iron, probably derived by oxidation from pyrite, were found in 1883 and are said to have assayed in small samples proportionate to $2500 per ton.[7] Similar material from near Mertzon in Irion County is said to have assayed proportionate to $237 per ton. At neither place was there enough of the ore to work.

Panning for gold.—Free gold either in veins or other bed rock deposits or in placer sands and gravels can be detected by panning. Panning is the process of causing the gold, which is heavier than the other substances, to settle to the bottom of a receptacle by a combination of rocking and semi-rotation of the receptacle. A frying pan, pie pan, hand basin, or dish pan can be used, but it is much more satisfactory to have a regular gold pan or a trough-shaped horn. A regular gold pan is about 18 to 24 inches in diameter and has a side which flares out much less steeply with respect to its bottom than in other pans. It is preferable that the gold pan should be rusty. Vein material must first be finely pulverized before it is panned. Sand or fine gravel of stream deposits, especially that lying directly upon the hard rock or found in pot holes or other kinds of depressions in the hard rock, is placed in the pan but not to its full capacity. Water is added, and the pan is rapidly swung back and forth and at the same time gently rocked, both hands being used in the operation. The coarser and lighter particles rise to the top of the solid material during the process, being scraped off from time to time and water added as needed. Much care must be taken with the final stages in which the original panful of "dirt" has been reduced to a teaspoonful or less of the heavy mineral residues. If any gold is present, it will be included in the residue usually along with a large percentage of "black sand" (magnetic oxide of iron). The final operation is a gentle rocking by means of which the particles of gold are concentrated at the higher point of the residue or "tailings" and thereupon become visible.

Horning is somewhat similar to panning but is done by rocking the horn to and fro in one hand and scraping the coarser and lighter material away with the other. In both panning and horning, the finer clayey material is removed from coarser particles by washing, that is, rubbing the "dirt" with the hand during the earlier stages of

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[7]Schaeffer, C. A., On the occurrence of gold in Williamson County, Texas: Trans. Amer. Inst. Min. Eng., vol. 11, pp. 318–321, 1883.

the operation. Clean sand or gravel, which contains little clay or finer "dirt," requires little "washing."

When gold occurs combined with pyrites, it cannot be detected by panning, and the value of the ore can be determined only by assaying.

For placer mining methods the reader is referred to "Gold placers of California," by C. S. Haley, California State Mining Bureau, Bulletin 92, 167 pp., 1923; and "Handbook for Prospectors," by M. W. von Bernewitz, published by McGraw-Hill Book Company, New York, 2nd ed., 359 pp., 1931.

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GREENSAND

Greensand is a hydrous iron silicate or iron chlorite of rather indefinite composition. The more usual varieties are differentiated as glauconite (containing potash, lime, magnesia, and alumina), chamosite (containing magnesia and alumina), thuringite (containing alumina), and greenalite (containing only iron, silica, and water). It is probable that in many cases mixtures in some proportions of two or more of the above occur.

All greensands in Texas have been called glauconite, but it may be doubted whether any true glauconite occurs in quantity in Texas except in the Upper Cambrian strata, where it is present in a relatively small percentage of the whole rock as a matrix of sand grains or as disseminated small particles in limestone. The greensands of the Upper Cambrian and Eocene strata weather to characteristic brick-red soils. Greensand occurs also in the Midway Eocene formation, that from Leon Creek 7 miles west of San Antonio analyzing 1.69 per cent potash and 3.3 per cent phosphoric acid, the latter being in small disseminated nodules or pebbles.

No greensand known in Texas contains a percentage of potash sufficient to be of value for the exploitation of the latter, although potash-bearing greensand forms valuable residual soils, especially if they are treated with pulverized gypsum or anhydrite from which sulphuric acid is slowly generated and releases the otherwise relatively very slowly soluble potash from the original silicate.

Perhaps the only present known use for the greensand is as a water softener in the zeolite or permutit process. For a water softener the greensand after being washed and sun-dried is screened so as to get a sand most of the grains of which will pass through a 20-mesh and be retained on an 80-mesh screen. It is treated with a sodium salt, the sodium replacing a part of the potassium. Hard water will then be softened as it filters through a properly constructed apparatus. Daily regeneration of the filtering material is brought about by temporarily running through the greensand a solution of common salt in water, the sodium thereupon replacing the calcium or magnesium, the latter going into solution as chlorides and being washed out.

It is obvious that only potash-bearing greensand can be used in the process. Not all the Claiborne Eocene and other Cretaceous and Eocene greensands contain potash in quantities sufficient for a water softener.

IRON MINERALS AND ORES

Iron, the most useful of all metals, is the fourth most abundant element in the surface part of the earth. Its oxides, carbonates, and silicates produce most of the coloring matter in rocks and soils.

Iron compounds are so abundant that they can be detected in almost all analyses of rocks, minerals, water, plants, and animals. Some 265 minerals contain iron as an essential part of their composition.

PRINCIPAL ORES AND MINERALS

Metallic iron, alloyed or in the pure state, occurs on the earth only in relatively small quantities. The metal, generally alloyed with some nickel, is found in large masses as well as in small embedded particles in Disco Island, West Greenland, and in small grains in igneous rocks from a single locality in each of the following countries: Germany, New Zealand, British Columbia, and Ontario, and in the state of Oregon. Native iron also occurs sparingly in some basalts. It is brought to the earth also in meteorites. According to one of the world's leading students of iron ores, it is possible that metallic iron or at least iron oxide in practically pure state has been erupted as an igneous rock in pre-Cambrian times. The main ores of iron are the oxides, magnetite ($FeO\ Fe_2O_3$), hematite (Fe_2O_3), limonite ($2Fe_2O_3\ 3H_2O$), and goethite ($Fe_2O_3\ H_2O$); the carbonate, siderite ($FeCO_3$); and, subordinately and as by-products, the sulphides, pyrite (FeS_2), chalcopyrite ($CuFeS_2$), pyrrhotite (FeS), arsenopyrite ($FeAsS$), and marcasite (FeS_2). The oxides, magnetite, hematite, and limonite, constitute the most important ores. The hydrous iron silicates, glauconite, thuringite, greenalite, and chamosite, are considered to be sources from which many of the iron ores were derived by residual concentration.

OCCURRENCE IN TEXAS

There are three types of iron ores in Texas, namely, residual sedimentary ores, later metamorphosed, in the Llano uplift of central Texas; supposedly residual or lateritic hydrated ores of east Texas; and economically unimportant contact metamorphic deposits in limestones on and near the contact with intrusive igneous rocks in Trans-Pecos Texas.

MAGNETIC IRON OXIDES OF THE LLANO UPLIFT, LLANO AND MASON COUNTIES

The iron deposits of the Llano uplift are mainly in Llano and Mason counties. They are bedded or layered in association with rocks which were originally sedimentary and were later metamorphosed and strongly deformed by dynamo-regional processes.

The metamorphics are intruded by offshoots from a granitic batholith, the intrusives being generally in accordance with the strike of the metamorphics and for the most part later in age than the regional metamorphism. The granites of this region are remarkably free from the action of hot gaseous or aqueous mineralizers and, therefore, show much less alteration of feldspars and micas than granites generally. Accordingly, relatively little contact metamorphic mineral deposits have been developed in the area, and the intrusives seem to have had little or nothing to do with the formation of the iron deposits.

The magnetite ore is either fairly pure, occurring as one or more beds in gneisses or schists, or else is disseminated in magnetite schists or gneisses where it contains much quartz and feldspar. In the majority of cases the continuity of the ore bands is disrupted by granitic intrusions, faults, or local squeezings by thrusts. At and near the surface the magnetite is now altering to martite, an isometric (commonly octahedral) sesquioxide pseudomorphous after the magnetite. Alteration in most cases is, however, not complete because the martite retains some of the magnetic property of the original magnetite. Dark red soils, colored by martite, hematite, or turgite, are in some places indicators of subsurface magnetite deposits but in many places in the district occur also as a weathering product of the Cambrian Hickory formation. The iron sulphide, pyrrhotite, in places occurs with the magnetite, as at Iron Mountain, 1 mile northwest of Valley Spring, northwest Llano County.

Specular hematite, containing medium-sized crystals of quartz and feldspar, has been found near the magnetite ore on or near the Fleming place near old Fly Gap post office, northeastern Mason County. Its origin and relationships are still unknown.

None of the numerous magnetite deposits has been adequately prospected, there not being sufficient incentive because there has been no market demand for the ore. The faulting, folding, granitic intrusions, and squeezing out of the ore bands during thrusting render known deposits fairly spotted and discontinuous. Most of what prospecting has been done is wasted effort because of inadequate comprehension of the structural complexities. Prospecting for this magnetite, as well as in so many other places and conditions, must follow the ore regardless of where it leads. Tunnels or shafts sunk on ill-conceived theories concerning where the ore ought to be will in the majority of cases encounter nothing but barren country rock. In some cases dark red, weathered residual soil will indicate deposits of magnetite beneath, but such soils are even more plentiful as a weathering product of non-metamorphic sediments of the Cambrian and basal Cretaceous. In many cases the magnetite deposits are covered by non-red soils and gravels transported to present sites from other areas. In such the magnetite has been found by pure accident in excavations made for other purposes, as in the case of the Olive mine, on Little Llano River, 1 mile downstream from Lone Grove, Llano County. Surface soils and débris cover all but a fraction of 5 per cent of the gneiss and schist areas, most of the outcrops of which occur along stream and artificial excavations. The natural stream excavations increase to the southeast, in the vicinity of the Sandy Creek drainage basin, where there is more stream trenching caused by rejuvenation progressing upstream in the Colorado River basin.

Fortunately, all the ore is magnetic and, therefore, where buried can be detected by magnetometric methods. Where on or close to the surface the magnetite will deflect the needle of an ordinary compass, and the dip needle can be used to good advantage. The dip needle will serve to trace the underground extensions of known magnetite deposits. What is needed, however, and what will doubtless be done sooner or later, is a thorough magnetometer survey of the whole area including the territory still covered by the Paleozoic sedimentary rocks and also the marginal area now covered by the Cretaceous. A complete magnetometric survey of the whole prospective area will cost only a few thousand dollars and has very fair prospects of discovering important concealed bodies of magnetite ore. The magnetometer alone will afford considerable data concerning the richness, size, and depth beneath the surface of the deposits. Then further blocking out of reserves will be done by diamond core drilling and analyses of the cores. Perhaps such investigation must await the development of a demand for the ore, which demand does not exist at present and will probably not exist for a generation; however, a sufficiently far-sighted corporation will in the meanwhile investigate with a view of procuring mineral rights on reserves for the future.

The magnetite ores now known are sufficiently low in phosphorous to be well within the Bessemer limit and their content of sulphur is not excessive. Their concentration by magnetic process is simple and relatively inexpensive. Climatic conditions are extremely favorable for all-year-round workings and the distance of the deposits from Houston deep-water harbor will not average more than 250 miles by railroad. Spencer and Paige[8] describe 32 occurrences of this ore. Other important occurrences are in the neighborhood of Fly Gap in northeastern Mason County.

The original iron deposits in the sediments before metamorphism were probably oxides. The oxides may possibly have been original residual concentrations from silicates, but this is conjectural. It is not likely that the magnetite was formed by metamorphism directly from silicates for the latter did not contain sufficiently high percentage of iron, nor from carbonates because carbon dioxide would have had to be eliminated and it was not eliminated from adjoining limestones, now marble. Dynamo-regional metamorphism seldom adds or substracts substances and in this particular case especially this would be true because the original iron deposits were interbeds in impervious shales.

OXIDE, SILICATE, AND CARBONATE IRON ORE OF NORTHEASTERN TEXAS

The iron ores of northeastern Texas are low in phosphorous. The iron made in the state furnace at Rusk was too pasty to make good tubular goods but for other purposes was a good grade of charcoal iron. The ores occur in the Mount Selman group of the lower Claiborne Eocene. Most of the ore is limonite forming the capping of high and rugged hills and ridges, the ore varying from 2 to 5 feet in thickness, either without overburden or with an easily removed overburden, generally less than 6 feet in thickness consisting of sands, clays, and thin sandstones. Kennedy divided the ores into (a) nodular concretionary; (b) laminated, sheeted, or layered; and (c) soft, brown, laminated. The ores are concentrated in the northeast Texas syncline.

The following data and estimates are quoted from "The mineral resources of Texas," by W. B. Phillips, University of Texas Bulletin

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[8]Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: U. S. Geol. Surv., Bull. 450, pp. 12–13, 1911; and Description of the Llano and Burnet quadrangles: U. S. Geol. Surv., Geol Atlas, Llano-Burnet folio (No. 183), pp. 26–70, 1912.

365, pp. 13–14, 1914. The approximate total area, not all commercially ore-bearing but the area in which workable ores may be found, is estimated as follows by counties:

County	Square Miles
Anderson	47
Cass	350
Cherokee	350
Gregg	22
Harrison	245
Henderson	19
Marion	27
Morris	15
Smith	81
Upshur	10
Wood	25
Total	1191

Undefined areas in Panola, Sabine, Shelby, Rusk, Nacogdoches, Van Zandt, Houston, Franklin, Titus, Camp, and Hopkins counties may bring the total up to 1250 to 1300 square miles. Kennedy estimated that there are 550 square miles of workable deposits in the state, some of which will produce as much as 7,000,000 tons per square mile.

Mr. E. A. Wendlandt, in a private communication to the writer, states that he considers the estimate in the above table low for Anderson, Marion, Morris, and Upshur counties, and much too great for Harrison County. Weight should be given to his opinion, because he has devoted much effort to areal mapping and study in northeast Texas. Accordingly, the following is quoted from his letter, which is a different interpretation than that upon which the tonnage and acreage estimates given above were based.

Where the Weches is at a relatively high position structurally and does not have any more than, say, 10 or possibly 15 feet of Sparta overlying, I am inclined to believe that the iron ore will be found, although not as thick as where the overburden is less or at the outcrop along the edges of the mesas, ridges, etc. In other words, the thickness of the ore in general increases, with a decrease in thickness of Sparta. The same thing holds true of the Reklaw ores. Where there is a considerable thickness of chocolate clays above these greensands, core tests have shown that only greensand is encountered and no ore. In areas where the Weches is structurally low, such as in local synclinal areas of Smith and Cherokee counties, there is very little, and in places no, ore developed at its top. I have also observed in about 12 instances that where wells started considerably above the Weches (from 40 to 300 feet above the base of the Sparta) only greensand was encountered and no iron ore. Two of these wells were located in Smith County, one in Anderson County, and the remainder in Houston and Leon counties.

It may be commented that in the four counties noted in the last sentence quoted, good iron ore is known to be relatively scarce; hence the results of the core tests may not have any particular significance as concerns the more productive areas. Mr. Wendlandt considers that his mapping proves that the horizon at the top of the Weches greensand contains most of the workable ore.

Shipments of roughly screened but not washed or calcined ore carried from 55 to 57 per cent of metallic iron. But considering all the material which would have to be moved by steam shovel, large and continuous operations would produce ore ranging from 30 to 35 per cent metal. If this is washed, jigged, or otherwise improved by ore-dressing, the percentage of iron could be increased to 55 or 60 per cent and the manufacture of pig iron in the furnace rendered less expensive.

The total production of iron ore in northeast Texas is about 600,000 tons, valued at $600,000. It is estimated that the value of pig iron produced is about $3,000,000. No ore is being mined at the present time.

STRATIGRAPHY

The condensed and generalized section of the iron-bearing Claiborne group of middle Eocene age of northeast Texas is as follows:

Cook *Mountain sub-group:*

6. Crockett, predominantly clay, much of which contains iron silicates, with subordinate limestone lentils and sands. Thickness varies up to at least 450 feet. Equivalent to the original Cooks Mountain of Kennedy plus the Nacogdoches formation of Dumble.
5. Sparta, mainly sand, but with considerable clay and minor amounts of iron silicate, limonite, and lignite. Thickness from 230 to 300 feet.

Mount Selman sub-group:

4. Weches or main iron ore member, at least in southern area. Laminated iron ore member occurs at the top. The balance is mainly clayey iron silicate and clays with some sands and a little limestone. Some concretions and nodules of iron carbonate. Thickness from 50 to 150 feet.
3. Queen City, upper sands with bentonite and lignite, 200 to 230 feet thick. Middle member or Omen "greensand" (iron silicate member), 10 to 15 feet of greensand; maximum thickness of Omen is 30 feet. Lower sands and clays, 140 to 150 feet thick.

2. Reklaw clay and subordinate sand with iron silicate, carbonate, and some impure lignite. Thickness up to about 200 feet.
1. Carrizo sands, with considerable iron and carbonaceous content and some sandy clay. Thickness up to 80 feet.

The Crockett, Weches, and Reklaw contain an abundant marine fauna. The Sparta, Queen City, and Carrizo sands may be for the most part at least non-marine in outcropping exposures. Most geologists consider that there is an unconformity at the top of the Wilcox, and very likely there are a number of diastems (intervals of non-deposition), some more local, others more regional, between various members of the Claiborne group and perhaps within the members as well. Shallow Gulf waters appear to have alternated with land conditions during the Claiborne, there being four land and three shallow Gulf episodes during Claiborne time.

Wendlandt and Knebel[9] state that the Queen City decreases in thickness towards the northeast in Cass County and that it contains only a few isolated bodies of workable iron ore, the best of which are in the Omen greensand member. They say also that the Weches becomes more sandy towards the northeast, especially in Cass County, the iron ore occurring irregularly throughout the member, and that concretions of siderite are found almost throughout the Weches greensands. They state that there is almost no commercial iron ore in the Reklaw member but that it contains zones of clay ironstone concretions and considerable interbedded greensand.

The careful observations and conclusions of Kennedy[10] apparently confirm those of Wendlandt and Knebel. In the following quotation from Kennedy, the word "Queen City" should be substituted for "lignitic" because when Kennedy wrote, the Queen City was considered to be the upper member of the "lignitic" (now Wilcox), and the various greensand horizons had not been differentiated.

After an exhaustive examination of the lignitic beds throughout their greatest extension in the regions in which the nodular ores form the prevailing ore-deposits, and also an extended series of examinations covering the greater portion of the territory devoted to the laminated ores as well as many hundreds of square miles of lignitic areas, in which no ore of any grade exists, the

[9]Wendlandt, E. A., and Knebel, G. M., Lower Claiborne of east Texas, with special reference to Mount Sylvan dome and salt movements: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 1347-1375 and geologic map, 1929.

[10]Kennedy, William, Iron ores of east Texas: Trans. Amer. Inst. Min. Eng., vol. 24, pp. 267-270, 1895.

writer has come to the conclusion that all the ore-deposits, whether nodular or laminated, are of one and the same age, and that the existence of the nodular ore in that form is due altogether to the disintegration and consequent destruction of the greensand deposits.

As has been observed already, the uppermost deposits of the lignitic beds are a series of thinly laminated white and red sands and sandy clays, which lie in direct contact with the lowest members of the greensand deposits of the marine beds. These laminated deposits, wherever seen, have a covering of iron or ferruginous sandstone, varying from half an inch to one inch in thickness, and below which not one of the extensive ore-deposits of any kind is ever found.

Small quantities of nodular ore do occur in some portions of the lignitic beds but these are usually found at considerable depths, and are never extensive. Many of these nodules have the peculiarity, where hollow, of being filled with water; sometimes these nodules contain ocher; and I have yet to see one containing sand. It must also be borne in mind that throughout the very extensive range of country embracing the northern half of Robertson, great portions of Limestone, Henderson, Wood, and Smith counties, as well as the southern portion of Harrison and northern half of Panola counties, all of which are covered exclusively by lignitic deposits, no bodies of nodular ore exist. Occasional nodules are met with in digging wells; but these are generally small and unimportant.

The assumption that the nodular ores belong to the lignitic, both by Johnson, who first made the statement, and by Penrose, who apparently followed him in this as in several other statements, appears to have arisen from the generally accepted idea that this class of ore is found only in the lignitic areas of the State, and that the region embraced by Cass, Morris, Upshur, and Marion counties, in which the nodular ores form the most abundant class of iron, is occupied altogether by deposits of the lignitic series.

While it may be admitted that the greater extent of the territory covered by these counties is occupied by beds belonging to the lower, or lignitic division, this class of deposits does not form the whole of the region. Widely spread fragmentary deposits of greensand marls and glauconitic sandstones occur in many portions of Cass, Morris, and Marion counties. These fragmentary deposits often cover several miles of territory, and their presence is always marked by the occurrence of heavy deposits of nodular ore and a greater or less extent of broken fragments of laminated ore.

In Cass County altered greensand belonging to the marine beds occurs, in association with both nodular and laminated ore, at the Berry Crawford mine, scarcely a mile north of Atlanta Station. Here the nodular overlies the laminated ore and the altered greensand underlying the ore-deposits rests directly upon the uppermost deposits of the lignitic series. The same ridge extends northwesterly and northerly for several miles; and nodular ore is found buried in a brownish-gray to yellow sand forming the summit and sides of the ridge. The region around Hughes Springs, in the same county, is covered for several miles with broken deposits of laminated ore, resting upon beds of pyritiferous greensand. These beds extend westward to and beyond Daingerfield, and southward to near Little Cypress Bayou in Morris County. In this area, both laminated and nodular ores occur in close association. These deposits rest upon the same laminated white and red deposits seen in the Berry Crawford mine region. Altered greensand, associated with ore and sandstone of the same age, occurs also near Cusseta Post-Office in the northern portion of Cass County.

Coming southward into Marion County, the laminated buff crumbly ore, associated with ferruginous sandstone and nodular ore occurs on a small hill, about two miles north of Jefferson. Here also these deposits rest upon the laminated red and white sands and clays of the lignitic. Another deposit of greensand occurs in the banks of Cypress bayou, close to the town of Jefferson; and in the northwestern corner of the county there is a continuation of the same beds seen in Morris and western Cass County.

An extensive area overlain by these glauconitic marine deposits forms a high ridge through the center of Harrison County. The eastern or northeastern end of this ridge lies about six miles north of the town of Marshall, and the western end extends a short distance west of the western line of the same county. This area is fossiliferous, to some extent, throughout. The fossils, however, usually occur only as casts, and belong to the fauna common to the lower Claiborne greensands. Both nodular and laminated ores occur in close association on the top of some portions of the ridge, and many nodules of the same grade lie amongst the broken laminated ore along the sides and in the stream-channels flowing through or from the ridge. This ridge is cut off from the northern deposits by Little Cypress bayou and the bottom-lands belonging to that stream, and its western extension is cut short by the Sabine River and its associated flat-lands. The glauconitic deposits of the ridge itself rest directly upon the uppermost stratified deposits of the lignitic, whose white and red ribbon-like sands and clays crop out everywhere along the base of the ridge, and in some of the deep cuttings extending through the area. A small outcrop of altered greensands, with thin laminae or strata of laminated ore, occurs on the north side of Little Cypress, at Allen's Bridge. The intimate association of these altered sands with the ore can readily be understood when it is stated that the latter lies interstratified with and filling numerous joints in the sands.

In Smith County, also, we find isolated hills of sands and laminated ores belonging to the same age. A hill half a mile west of Swann Switch shows this structure, and about nine miles southeast of Tyler a ridge, showing laminated ore, rests directly upon the altered greensand, containing casts of lower Claiborne fossils.

It must be remembered that these are all detached areas, separated by wide intervals from the main body of the greensand deposits, and these denuded areas are occupied by streams, some of which are of considerable size, and to the action of which a great part of the denudation may possibly be due.

The position of the nodular ores in relation to the laminated variety is somewhat difficult to determine exactly. In many places we find them overlying the laminated deposits; but, at the same time, it must be admitted that the greater portion of these ores lie at considerably lower levels. The lower-level ores, however, all occur in positions unconformable with and overlying the uppermost deposits of the lignitic. With but very few exceptions the nodules or geodes of ore, irrespective of their positions, are intermixed and interbedded with a brownish-gray or yellow sand, of the same texture and appearance as that usually found overlying the laminated ore-beds of the regions exclusively occupied by that class of ore. These nodules are not infrequently mixed with broken fragments of the laminated variety.

From these facts it would appear that the whole area was at one time completely covered by the marine beds, with their associated deposits of ore, and that through a prolonged period of erosion these deposits have been gradually broken down and destroyed. The iron, by a process of leaching and segregation, has acquired the nodular form in which we now find it. The theory advanced by Dr. Hilgard[11] for the formation of these ores, as applied to their orange-sand origin, *viz.*, that these nodules have been formed along the line of contact between the orange sand and the underlying lignitic clays by the oxidation and lixiviation of the iron from the sands, may as well be applied to their formation from the destruction and consequent ferrugination of the glauconitic material contained in the marine Tertiary beds. This erosion is going on rapidly at the present time.

Returning to Mr. Johnson's idea that the laminated ores are lacustrine and were produced at various stages of the Quaternary history of the region under consideration, and some of them possibly during the Tertiary,[12] the examinations made throughout the region show very conclusively that none of these ores belongs to any portion of the Quaternary, but the whole of the laminated ores are connected with, and form an integral part of, the marine beds. Many of the sections examined in widely separated portions of the country show the same character of ore to occur at more than one horizon and to lie interstratified with the glauconitic beds. Borings in many places have demonstrated the existence of these ore-deposits within the interior of the beds, so that they are not solely due to atmospheric action. These lower deposits are usually much thinner than the upper, or what may be denominated the surface or main body of ore. Besides being thus connected stratigraphically with the greensand beds, the ores themselves are fossiliferous and carry a fauna similar to that of the greensand beds, and therefore belong to the marine or lower Claiborne stage of the Tertiary.

The sections of the iron-bearing formations which follow are taken from the published reports of Penrose, Kennedy, and Burchard. The area northeast of Sabine River will be considered first and the southern area afterwards. The sections are given in descending order, with the highest bed at the top.

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[11]Hilgard, E. W., Report on the geology and agriculture of the state of Mississippi, pp. 23–24, Jackson, 1860.

[12]Johnson, L. C., The iron regions of northern Louisiana and eastern Texas: U. S., 50th Cong., 1st sess., H. Doc. 195, 54 pp., 1888.

Penrose[13] gives the following section of Johnson's Hill, 3 miles north of Lassater, northern Marion County:

	Thickness *Feet*
1. Ore bed, stratified and in geodes, brown and black, bed much broken, interbedded with seams of sand	4 to 10
2. Ferruginous and mottled clays	3
3. Ore, similar to the stratified part of 1	¼ to ⅔
4. Interbedded ferruginous sands and clays	20
5. Mottled red and white sandy clays	10
6. Red ferruginous sandy clays	65

Kennedy's[14] section one-half mile north of Queen City, Cass County, is:

	Thickness *Ft.*	*In.*
1. Gravelly ore and broken pieces of nodular ore, sandstone and sand	5	
2. Laminated ore	4	
3. Stratified white and red sand, with white sandy clay	65	
4. Brown sand, with clay mixed at various depths	25	
5. Lignite	1	6

His[15] section in a cut on the Missouri, Kansas, and Texas Railway, 3 miles west of Hughes Springs, Cass County, is:

	Thickness *Feet*
1. Red ferruginous sandy soil, with thinly bedded iron ore and ferruginous sandstones	10
2. Stratified brown and white sands, with a broken bed or pavement of nodular ore near center of bed; ore 1 foot thick	4 to 6
3. Black laminated sandy clay, containing rounded boulders of ore and sandstone and showing efflorescence of pale yellow	8

Kennedy[16] gives the following section on the W. C. Allan headright, Harrison County:

[13]Penrose, R. A. J., Jr., A preliminary report on the geology of the Gulf Tertiary of Texas from Red River to the Rio Grande: Texas Geol. Surv., 1st Ann. Rept., p. 78, 1890.

[14]Kennedy, William, Description of counties, *in* Reports on the iron ore district of east Texas: Texas Geol. Surv., 2nd Ann. Rept., p. 72, 1891.

[15]Kennedy, William, *op. cit.*, p. 73.

[16]*Op. cit.*, p. 121.

	Thickness Ft.	In.
1. Brownish gray sand, seen a few yards back from edge of bluff	3	
2. Conglomerate ore in blocks measuring from 18 inches to 2 feet. This conglomerate is hard and solid and forms surface of bluff at edge	2	
3. White sand stained yellow in places. This sand is hard and compact	6	
4. Laminated iron ore, with thin overlying stratum of sandstone; iron of massive variety		4
5. Greenish yellow spotted sand in a compact form, somewhat glazed on outer surface but broken with numerous irregular fractures filled with iron, giving the face of the bed a reticulated or net-like appearance	10	
6. Laminated ore and ferruginous sandstone	2	
7. Greenish yellow sand spotted with round dirty white or gray spots. In other respects this bed resembles No. 5	10	

Iron silicates or carbonates are absent from the above sections, suggesting either that they do not occur or else that they have been altered entirely to limonite. However, Burchard's sections of strata exposed by prospecting in Cass County show that limonite is associated with iron silicates and with iron carbonate. The following are Burchard's[17] sections:

Generalized section of ore-bearing beds on Bowie Hill, Cass County.

	Thickness Feet
Residual fragments of limonite in top soil, in places practically solid ore gravel	1–3
Ledge of nodular limonite, more or less solid	½–1¼
Scales and thin bands of limonite, with a few thicker layers or ledges interlaminated with glauconitic sandy layers. The limonite in this condition ranges from pieces of the thickness of small chips up to masses 1½ feet thick and is scattered through yellowish to red sand and clay. It occurs in overlapping, roughly lenticular streaks, or broken and discontinuous seams. The limonite constitutes, in the sections observed, 20 to 30 per cent, by volume, of the dirt. Thickness of limonitic sand and clay	12–15
Iron carbonate in nodular masses from the diameter of an acorn up to 6 inches, or in thin irregular lenses, embedded or interstratified in glauconitic sand and greenish-black clay called "buckfat" clay. The iron carbonate is in general partly altered	

[17]Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee counties, Texas: U. S. Geol. Surv., Bull. 620, pp. 76–81 1916

	Thickness *Feet*
to limonite or to reddish hydrated oxides of iron, which form a scale or crust of varying thickness around the carbonate nucleus and along cracks which intersect the masses. Thickness of exposed portions of the unoxidized beds	1–5

A section of the upper portion of the ore-bearing ground measures in detail as follows:

Section of cut at east end of Washer trestle, Bowie Hill, Cass County.

	Thickness *Ft.*	*In.*
1. Soil, roots, and limonite débris	1–6	
2. Limonite in layers 1 inch to 4 inches thick		8–12
3. Reddish-yellow sand, in part glauconitic		9–15
4. Limonite ledge with wavy and crumpled layers		6–15
5. Yellowish-red glauconitic sand with ocherous nodules and flakes		½–11
6. Limonite ledge with wavy and crumpled layers interstratified with a little yellowish clay and glauconitic sand. (Nos. 4 and 6 come together, No. 5 forming a wedge between)		1–5
7. Reddish clay and yellow sand, mostly glauconitic, with ocherous nodules and lenses	1	1–3
8. Limonite in ½-inch to 2-inch bands, interstratified with glauconitic sand and running into ocher		2–3
9. Yellow glauconitic sand, with small ocherous lenses		10
10. Limonite streak running into ocher		¼–1
11. Yellow glauconitic sand		3
12. Ocherous clay		1
13. Yellow glauconitic sand		4
14. Limonite ledge, with slightly wavy laminae containing thin seams of ocher and glauconitic sand	1	9
15. Yellow sand, not glauconitic		1
16. Limonite ledge, base concealed		1

Other members besides No. 5 of this section are more or less wedge-shaped as exposed, and the great variability in thickness and extent of all the brown ore members is easily demonstrated by the use of a pick and is shown in the following two sections, displayed 35 feet apart in the same trench:

Section at face of trench south of uagon road, Bouie Hill, Cass County.

	Thickness *Ft.*	*In.*
Soil and brown-ore débris	2	4
Reddish sand		8
Limonite		6–11

	Thickness Ft.	In.
Reddish sand		10–14
Limonite		2½–6
Reddish glauconitic sand with light clay streaks		20–24
Limonite		2–6
Reddish glauconitic sand with four thin crusts of limonite	1	1
Reddish glauconitic sand with light clay streaks	1	3
Limonite		4
White and yellow clay and glauconitic sand		3–4
Limonite		3–4
White clay and yellow glauconitic sand	1	0
Limonite		4–6
Reddish-yellow glauconitic sand	1	3
Reddish clay, becoming greenish black at base		6–7
Iron carbonate, concretionary layer		6

Base concealed by water.

Section at side of trench south of wagon road, Bowie Hill, Cass County.

	Thickness Ft.	In.
Soil and limonite débris	2	1
Limonite layer, broken and interstratified with glauconitic sand and clay		7
Reddish clay and glauconitic sand containing limonite fragments	1	6
Limonite streaks and crusts in glauconitic sand and clay (about 25 per cent limonite)	2	6
Yellow glauconitic sand with white clay streaks	1	4
Limonite, in wavy and honeycombed layer		6
White to reddish clay		7
Limonite, in irregular seam		1–2
White to reddish clay with limonite fragments		5–8
Limonite		11
Yellow glauconitic sand		7
Ocherous sand		1
Yellow glauconitic sand		3
Limonite and ocherous sand		2–3
Yellow glauconitic sand and ocherous nodules	1	0
Limonite		¼–1½
White clay		1
Yellow glauconitic sand with white clay streaks and a little limonite		7

Base concealed by water.

Section of prospect trench on Bowman Creek 4½ miles north of Linden, Cass County.

	Thickness Ft.	In.
Top soil and sand, with lumps of indurated glauconitic sand	2	3
Nodules of limonite		3
Sand and clay		2
Limonite		2–4
Reddish clay and glauconitic sand		10
Ore-bearing material, consisting of glauconitic sand with a little red clay. Contains 20 or more thin seams of limonite, ¼ to ½ inch thick. These seams lie practically flat. Some of them are sandy, and many are coated with layers of glauconitic sand, part of which may be separated by washing. Some of the glauconitic sand is indurated in thin seams	4	10
Glauconitic sand and white to yellow clay	1	0
Limonite		3
Glauconitic sand and white to yellow clay		8
Limonite		2
Glauconitic sand and white to yellow clay		3
Limonite		3–4
Glauconitic sand with fragments of limonite	2	6
Limonite		3
Glauconitic sand		3
Limonite		2½
Glauconitic sand	1	3
Limonite mixed with sand		7
Glauconitic sand with 18 to 20 streaks of ocherous limonite	8	4
Iron carbonate altered to limonite on top. The carbonate ore contains flakes of lignite		5
(A shaft has been dug below the level of the trench at this point and is reported to show yellow to greenish glauconitic sand and iron carbonate down for a depth of 36 feet.)		
Reddish-yellow glauconitic sand with a little red clay and much limonite in broken seams, fragments, and isolated nodules. This material has been estimated as capable of yielding 25 to 30 per cent by volume of limonite	10	6
(Here the section begins 50 feet nearer the slope of the hill, in oxidized material again.)		
Greenish-white clay with a few streaks of glauconitic sand and a little limonite. The lowest seam of limonite is 1 to 3 inches thick and appears to be the base of the ore-bearing material	4	4
White to yellowish fine sand containing a little clay	5	0

Section in prospect trench 5½ miles southeast of Linden, Cass County.

	Thickness Ft.	In.
Soil, sand, and limonite débris	2	6
Limonite, in thin plates		6–8
Reddish-yellow (oxidized) glauconitic sand	3	0
Limonite		10
Clay and reddish-yellow glauconitic sand		3
Limonite		1½
Grayish-white clay		3
Reddish-yellow glauconitic sand		9
Limonite		4–6
Reddish-yellow glauconitic sand		6
Limonite		½
Reddish-yellow glauconitic sand		2½
Limonite and oxidized glauconitic sand		7
Greenish-black (unoxidized) clay, or "buckfat"		11
Greenish (unoxidized) glauconitic sand		4
Iron carbonate, nodular ledge		4
"Buckfat" clay		4
Iron carbonate, nodules		3
"Buckfat" clay, base not exposed.		

Section in old mine trench 8½ miles southeast of Linden, Cass County.

	Thickness Ft.	In.
Soil and residual limonite, mostly in kidney-shaped concretions	2	2
Reddish cross-bedded glauconitic sand		9
Limonite in crusts and concretions		3
Reddish glauconitic sand with streaks of white clay and a few concretions of limonite		8–10
Limonite		1–2
Reddish glauconitic sand and white clay		7
Limonite		2–3
Reddish glauconitic sand and white clay		5
Limonite		1½
Yellow ocherous silica sand, base concealed		4

Section in large trench 9 miles southeast of Linden, Cass County.

	Thickness Ft.	In.
Soil rich in ore débris	1	0
Ledge of limonite with a few seams of sand	4	10
Glauconitic sand and clay		7–10
Limonite, in part concretionary		3–8

	Thickness Ft.	In.
Light-yellowish to reddish glauconitic sand		3
Limonite, in part concretionary		4–7
Reddish glauconitic sand and white clay, with a few small nodules of limonite; the sand is partly indurated by ferruginous streaks	1	9
Limonite		2–3
White and reddish glauconitic sand	1	11
Limonite lens, 3 feet long in sand layer		4
Limonite, with seams of indurated sand		10
Bluish-green clayey sand		3
Base concealed; iron carbonate reported below.		

Section in prospect trench 9 miles southeast of Linden, Cass County.

	Thickness Ft.	In.
Sand, light colored, mostly silica	1	6
Limonite		14–18
Reddish glauconitic sand, with white clay streaks and five streaks of limonite, ¼ to ½ inch thick	1	6
Limonite, with streaks of sand		4–5
Reddish glauconitic sand, cross-bedded, containing white streaks	1	11
Limonite		7
Yellowish sand		5
Limonite		2
Yellowish sand, cross-bedded		10
Limonite		4
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	7
Limonite		3
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	6

Section in southeast portion of trench cut through hill 9 miles southeast of Linden, Cass County.

	Thickness Ft.	In.
1. Soil and limonite débris		6
2. Limonite	1	7
3. Sand and limonite alternating in thin seams		7
4. Reddish-yellow glauconitic sand, cross-bedded, containing white clay streaks	1	11
5. Limonite		3
6. Sand, similar to No. 4		3
7. Limonite		4
8. Sand, similar to No. 4	1	5

	Thickness Ft.	In.
9. Clay		2
10. Limonite		3
11. Sand, similar to No. 4		2½
12. Limonite		9
13. Sand, similar to No. 4		8
14. Limonite		1-2
15. Sand, similar to No. 4	1	6
16. Limonite		1
17. Sand, similar to No. 4		10
18. Sand, similar to No. 4, containing two seams of limonite, each about 2 inches thick	10	0

Section near middle of trench cut through hill 9 miles southeast of Linden, Cass County.

	Thickness Ft.	In.
Soil and limonite débris		18-26
Limonite, in heavy ledge with lenses and "pots" of sand and clay	6	3
Yellow glauconitic sand, locally indurated, containing a few seams of limonite	3	4

The sections which follow are in Cherokee County, representative of the southern area. Penrose[18] made the following section 3 miles north of Rusk:

	Thickness Ft.	In.
1. Gray and buff sands	8	
2. Hard brown sandstone		1-3
3. Brown resinous laminated oxide ore	1-3	
4. Altered fossiliferous greensand	30	
5. Gray clay, stained by iron in places	5	
6. Dark gray sand, with glauconite specks and rusty pyrites, giving rise to many ferruginous springs	20	
7. Gray and chocolate clays, ferruginous in places	35	
8. Interbedded seams of gray and chocolate clay and fossiliferous glauconite marl, sometimes indurated and partly altered; nodules and lenses of clay ironstone	40	
9. Gray clay, with seams of sand, and some clay ironstone		5
10. Interstratified gray and chocolate clay		5
11. Lignite	1	
12. Chocolate clay	1-1½	
13. Lignite	1	
14. Chocolate clay	6	
15. Interbedded chocolate clay and small seams of lignite		⅛-½

[18]Penrose, R. A. F., Jr., *op. cit.*, pp. 31-32.

Penrose's[19] section just east of Gent is:

	Thickness Ft.	In.
1. Gray or buff colored sand	1–10	
2. Silicious sandstone capping		1–2
3. Brown laminated iron ore	2	
4. Indurated greensand with thin seams of clay and casts of fossils	45	
5. Coarse white clayey sand	20	
6. Dark blackish-brown sand, more clayey towards the base, nodules of rusty clay ironstone showing shrinkage cracks	31	
7. Brownish-gray sand	11	

Kennedy's[20] section of a hill near the Rusk penitentiary shows:

	Thickness Feet
1. Gray sand	20
2. Interstratified laminated ferruginous material, iron ore and altered greensand, the ferruginous material from 1 to 2 inches and the sand from 6 to 10 inches thick in the interbeds	40
3. Laminated or thinly stratified red and whitish blue sand and sandy clay	20
4. Mottled red and blue sandy clay, probably belonging to and forming the lower portion of No. 3	25
5. Red sand and ferruginous gravel, lying around base, probably derived from the upper beds	5
6. Brownish stratified and fractured sand, mottled in places	60
7. Grayish blue stratified sand, in creek at base of hill	3

Burchard's[21] description follows:

The deposits in the vicinity of Rusk that were examined by the writer are of a type entirely distinct from those of Cass, Marion, and Morris counties, which are regarded as of Mount Selman age. Instead of consisting of irregular, ramifying, and fragmentary masses of more or less nodular ore distributed through 15 to 30 feet of beds, as in Cass County, the Rusk deposit consists essentially of one solid and fairly continuous bed of limonite with almost no residual concentration of ore above and but little ore in seams and nodules below. The limonite bed near Rusk forms a cap near the top of the flat-topped plateau, at an altitude of about 600 feet, and is overlain by unconsolidated gray sand ranging from 1 foot or 2 feet to 25 or 30 feet in thickness. Over areas comprising several square miles there are undulations

[19]*Op. cit.*, p. 69.

[20]Kennedy, William, A section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico: Texas Geol. Surv., 3rd Ann. Rept., p. 101, 1892.

[21]*Op. cit.*, pp. 90–92.

in the altitude of the bed reaching a maximum of perhaps 30 feet, but in the absence of an adequate topographic map or of precise levels the altitude can not be accurately determined for any given place.

The ore bed ranges from 7 or 8 inches to 3 and even 4 feet in thickness, but the more common thicknesses are between 1 foot 3 inches and 2 feet 6 inches. At the top of the ore bed, however, is a "sand cap," or layer of more or less ferruginous hard sandstone, from half an inch to 4 inches thick. This sand cap may be split freely from the ore in mining. The ore bed is immediately underlain by a few inches of light-colored clay, below which are layers of sand and soft sandstone, some of which is glauconitic. The upper surface of the sand cap is not smooth but is crossed by shallow furrows extending N. 65°–70° W. The width of these furrows is 2½ to 3½ feet, and the height of the crests above the bottoms of the furrows is generally 2 to 3 inches. The sand cap is thickest on the crests of the furrows, but the furrowed surface is characteristic of the limonite also when stripped of its sand cap, although the furrowing is not so marked. At the base of the ore bed botryoidal and rootlike protuberances of limonite extend down into the underlying clay, so that the basal surface is very irregular and presents a strong contrast to the upper surface. (See fig. 5.)[23]

The ore itself possesses certain characteristics of texture and color that make it easily distinguishable from the ores of the more northerly counties. The color, for instance, is light brown or buff, several shades lighter than that of the ore of Cass County, except where the latter is ocherous. The upper 2 or 4 inches of ore generally has fine open laminae, parallel to the bed, lined with glossy black coatings, with here and there a spot colored bright red. The ore below the laminated layer presents a curly structure when freshly broken, in contrast to the more evenly concretionary type of ore in Cass and Marion counties. The ore with curly structure cracks and crumbles on weathering, and thus is known as "buff crumbly ore." Occasionally a cavity containing sand or sandy clay is found in the ore.

The Rusk ore is considered to carry a relatively high percentage of alumina, and there may be a relation between the presence of this ingredient and the light color of the ore. The ore from the top of the bed containing black-lined laminations is said by furnace men who have had experience in its use to contain a higher percentage of phosphorus than the rest of the ore in the bed.

Burchard's[24] section 2 miles northeast of Rusk follows:

	Thickness	
	Ft.	*In.*
1. Sand, fine grained, gray, with soil and grass at top	7	
2. Sandstone, hard, with streaks of limonite	1	5
3. Limonite, compact	1	
4. Sand, yellow, soft		5
5. Limonite, compact	1	3
6. Clay, white, base not exposed.		

[23]Figure not reproduced.

[24]*Op. cit.*, p. 93.

The presence of the white clay with an uneven upper surface directly under the iron ore suggests a possible unconformity, the white clay resembling a weathered and leached soil.

Kennedy[25] gives the following section showing five horizons of iron ore. This section beginning at the base in a ravine about 1600 feet north of mile post 23, Cotton Belt (St. Louis Southwestern) Railroad in northern Cherokee County, is as follows:

	Thickness *Feet*
Top	
1. Brown sand, gravel and iron ore	1
2. Irregular deposit of laminated iron ore	1½
3. Brown sand	2
4. Iron ore	1½
5. Ferruginous sand	3
6. Iron ore	1
7. Stratified altered greensand	3
8. Iron ore	1
9. Altered greensand	4
10. Iron ore	1
11. Altered greensand	2
12. Blue clay	2

The following detailed section at San Augustine, San Augustine County, from the top of the hill at Little Rock to the Gulf, Colorado & Santa Fe Railway north of the station, of strata now called Weches by Wendlandt and Knebel, was made by Baker and illustrates the secondary concentration of iron oxide at more than one horizon:

	Thickness *Feet*
Top	
1. Very ferruginous reddish-brown Lafayette, locally with pebbles or with hard coarse sandstone cemented by limonite.	
Unconformity	
2. Beach or reef bed of hard silicified and calcified greensand marl containing *Scutella*, *Ostrea*, *Pecten*, and large gastropods. This layer forms a ledge at the First Baptist Church around the top of the partly circular valley of White Rock and elsewhere on the top of the hill. Layer appears to be made up almost entirely of comminuted shells	10
3. Altered greensand with local layers of iron oxide	24

[25]*Op. cit.*, p. 93.

	Thickness Feet
4. Altered greensand with small calcareous nodules. Horn corals, *Venericardia, Corbula*, and other fossils	5
5. Thinly and irregularly laminated ferruginous layers with interbedded greensand lenses. Two feet below the top is a thin, harder, concretionary layer	7
6. "Shelly"-layered ferruginous greensand with slickensides	6½
7. Thinly laminated, shaly, chocolate-brown sandy clay, sulphurous and limonitic, with thin black carbonaceous lenses, flakes of selenite, and crystals of pyrite. Clay stickier and less sandy than member No. 9, varying from light bluish-gray and light chocolate to rusty in color. Upper layer is fine and bluish black in color. At the contact of this clay with the overlying greensand are falls of all three creeks of the vicinity	9½
8. Thinly and irregularly laminated limonitic layers with small lenses of greensand	4
9. Altered oolitic greensand clay, dark green below, dark brown above with *Corbula* and *Venericardia.* Has nodular, limonite-coated greensand clay ironstone (iron carbonate) at base. Massive, jointed, with slickensides common along joint planes, the slickensides coated a dark purplish color	9¼
10. Layer of ferruginous concretions, non-continuous, with concentric structure of shells of limonite around the outsides with a hard compact brown center, perhaps of iron carbonate, dotted with oolites of greensand. Average thickness	½
11. Altered clayey greensand like member No. 9. Fossiliferous	4
Total	79¾

IRON DEPOSITS

There are two classes of the workable ore. One is the nodular, concretionary, or geode ore and the other is the laminated. The first is more particularly prevalent at the extreme northeast in strata which are mostly ordinary sands with relatively little greensands (iron silicates), being perhaps the most abundant type in Cass County. Going southwards the laminated type of ore increases in importance, being in the majority even so far north as Harrison County while it forms nearly all the workable deposits in Cherokee County.

Kennedy[26] describes the nodular ores as follows:

[26]Kennedy, William, Iron ores of east Texas: Trans. Amer. Inst. Min. Eng., vol 24, pp. 267-270, 1895.

The nodular ore is usually found in the form of irregularly-rounded, oval and flattened or ellipsoidal nodules or boulders from a few inches to one to two feet in length. Outside, these present a smooth appearance and dull or earthy brown color. When broken, the shell presents a striated appearance of yellow and brown colors, formed by the alternate concentric rings of iron ore and ocher. These striations usually do not exceed one-fourth to one-half inch in thickness, but in some of the larger nodules the iron has a thickness of over an inch, and in many the yellow ocherous concentric rings are absent, in which case the whole shell, with the exception of the brown outer covering, is dark blue. The interior coating of the shell is often a glossy black. Many of these concretions are hollow; a great number, however, have the interior filled with a core of brown or yellow ocher, similar to that forming the yellow rings; others have dentritic formations of ore spreading through the center and having the ends fastened to the inner side of the shell. Some few, particularly of the flattened oval form, have the entire center filled with convolutions of the inner ring. Most of the rounded forms are either empty or filled with the same character of yellow sand amongst which they lie.

Burchard[27] states that: "Both the brown ore and the iron carbonate occur in nodular and geodal forms segregated in glauconitic sand and clay in thin lenses and irregular ledges, and also as more or less honey-combed thin sheets and layers, fine fragments, crusts, small isolated nodules, and irregular masses of almost endless variety. Unconsolidated material, residual from the breaking down of such masses, is found in many places at the surface."

Kennedy[26] states that: "The laminated ores vary in appearance as well as texture and thickness. In places these ores occur as thin laminae of dark brown or chestnut color, interstratified with similar laminae of bright orange or yellow. The laminae rarely exceed a quarter of an inch in thickness. At other places the ores become more massive, occur in beds from two inches to as many feet thick, and vary in color from a dark chestnut-brown to a lighter shade of the same color, with small irregularly disseminated patches of yellow showing throughout the mass. This ore also occurs in thin wavy laminae of from chestnut-brown to black color, usually having the spaces between the laminae filled with fine clayey material. This grade is usually of a fine crumbly nature, hence the name given to it of 'buff crumbly.' The laminated ores have also been made to include the botryoidal and mammillated forms frequently found intermixed with other ores."

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[27]Burchard, E. F., *op. cit*, p. 74.

Burchard's description of the laminated ores is given in the preceding section dealing with the stratigraphy.

STRUCTURE

Most of the northeast Texas workable iron ore is situated in the northeast Texas syncline. The remainder, which on the whole appears to be of less prospective value, occurs on the southward to southeastward dipping monocline of the Gulf Coastal Plain between Sabine and Trinity rivers. The dip turns from southward to southeastward west of Neches River. Southwestward from Trinity River the iron ore decreases. It becomes also thinner and more scattered in the eastern part of the syncline in Bossier, Caddo, and Webster parishes in Louisiana and to the northeastward in Arkansas.

The northeastern Texas syncline is on the inner northern and western border of the Sabine uplift. Its strike in northwestern Louisiana and southwestern Arkansas is east-west. Between western Cass and northern Smith counties, Texas, the axis turns gradually southwestward and in Smith, Henderson, Anderson, and Cherokee counties, Texas, it runs southward. South of Cherokee County the syncline becomes less deep and turns southeastwards, parallel to the southwest margin of the Sabine uplift, but its structural influence is not marked south of the Eocene outcrop.

The Sabine uplift, as shown by the Wilcox-Claiborne contact, is nearly square, the sides of the square running northwest and southwest. The sides extending southwestward are parallel to the strikes of the Appalachians and also of the Ouachita folds to the southwest of the northeast corner of Texas. The northwestward sides are parallel to the strikes of the Wichita and Arbuckle mountains, the Amarillo arch, and the Llano uplift (of central Texas). Both these strikes were developed during Pennsylvanian movements and the northwestward strike at least is apparently older, having been developed during pre-Cambrian times in the Llano uplift. The southwestward strike may be primitive also, being prevalent in the pre-Cambrian of Lake Superior region, in the Appalachian and part of the Ouachita geosynclines, and in the junction of the Paleozoic rocks with the Cretaceous and Eocene at the western margin of the Mississippi embayment between the northeast corner of Texas and southern Illinois and continuing farther to the northeast in the trend of the faults in the southern Illinois-western Kentucky fluorspar district, and parallel to the longer axes of the Cincinnati arch and Nashville dome, the last two of which began to develop during the Ordovician.

Both these lines of structure, at right angles to each other, have produced a mosaic structure on the Sabine uplift and adjoining areas. The salt domes of the southern part of the northeast Texas syncline and the Van oil field are aligned northeast-southwest. So are most at least of the oil and gas fields upon the Sabine uplift. A southwestward-plunging broad syncline heads up dip in the center of the Sabine uplift about midway between Shreveport and Mansfield, Louisiana. This is flanked to the northwest by a southwestward-plunging anticline running from the Bethany-Waskom gas field southwestward across Panola County, Texas. Mr. Paul E. M. Purcell* states that a southeastward-plunging anticline forks at Ore City, one prong running south to Jamestown and the other running northeast and ending with a closed anticline at Avinger. He also states that there is a series of local uplifts from southeast of Jefferson, Marion County, Texas, to Avinger in southwestern Cass County, and flanked to the southwest by the Kelsey anticline in western Upshur County and farther southeast by a low northwestward-plunging anticline near the north end of the East Texas oil field just north of Gladewater. Northwestward, beyond the trough of the northeast Texas syncline, is the southeastward-plunging Preston anticline of Grayson and Fannin counties, flanked to the southwest by a very broad southeastward-plunging syncline in which are situated the headwaters of the East Fork of Trinity River and the headwaters of Sabine River.

There is considerable probability that the oil fields on the higher part of the Sabine uplift have been localized at junctions of the two leading tectonic strikes. The resultant of the two strikes has produced a westward-plunging hemi-anticline producing the westernmost projection of the Sabine uplift. This hemi-anticline extends from east of Henderson, in Rusk County, westward through the southern part of the East Texas oil field and through northern Cherokee County to Neches River. Along the axis of this structure the iron-bearing Weches formation outcrops in the vicinity of Mount Selman. Cherokee County, at its highest elevation and there plunges westward at

*Personal communication.

the rate of about 70 feet per mile. From Mount Selman northward to Flint, in southern Smith County, the Weches formation lowers 250 feet or more in a northward direction. To the south of the axis, from Jacksonville, Cherokee County, eastwards to near Timpson, in northwestern Shelby County, is a graben zone of nearly east-west faulting. To the north, a syncline is reported in central Smith County.

Age of the Sabine uplift and northeastern Texas syncline.—The Sabine uplift has experienced a complicated, oscillatory history. Deep drillings have demonstrated a thick Lower Cretaceous section, the base of which has not yet been reached. It stood above sea level in the latter part of the Middle Cretaceous and was again submerged during the Upper Cretaceous. It was covered by Wilcox sediments, some marine zones of the Wilcox being present on its southernmost projection in the vicinity of Sabine River. The steepest marginal dips are on the southeast flank. This flank was being rapidly submerged during Wilcox time because borings in Sabine Parish, Louisiana, have demonstrated the abnormally large thickness of about 2500 feet of Wilcox sediments. The Wilcox thickens also in the trough of the northeast Texas syncline. The southeastern flank dips are steep in all strata below the middle of the Catahoula but appear to flatten out in the upper Catahoula. The outcrop of the Catahoula is about three times as broad on Red River as on the Sabine. It also broadens westward in Texas from the Sabine. The outcrop of the Catahoula is not deflected northwards into the trough of the northeast Texas syncline and bends but little northward into the Mississippi embayment, but the underlying Jackson reaches northward in the embayment to the latitude of Memphis and reaches westwards almost to Little Rock. The evidence, therefore, is that the Sabine uplift upwarped sometime after the close of the Eocene and before the end of the Catahoula deposition and that during this interval the northern two-thirds of the Mississippi embayment reached sea level. The upward movement of the Sabine uplift appears to have begun as early as the Wilcox but not as early as the Midway. The upward movement appears to have been in progress during Claiborne times, at least on the southeast flank, because the various Claiborne formations thin and some of them disappear eastwards towards Sabine River. According to Miss Ellisor,[28] the Yegua from

[28]Ellisor, A C., Correlation of the Claiborne of east Texas with the Claiborne of Louisiana: Bull. Amer. Assoc. Petr. Geol., vol 13, pp. 1335–1346, 1929.

Lufkin west overlaps Sabine Bayou and Milams members and rests directly on the Crockett. This apparently would mean uplift of the southeast flank of the Sabine uplift and downwarping of the northeast Texas syncline near the end of the lower Claiborne.

The final uplifting of the Sabine uplift may, however, be as late as early Pliocene, perhaps even later. There is no really definite evidence of the age of the Catahoula; there is still a possibility that part of it, at least, may be as young as Pliocene. There is, moreover, abundant evidence that all "positive" areas from Florida to the Pacific Coast of California have experienced upward movements very late in the Cenozoic in Pliocene and even Pleistocene. Because the territory of the Sabine uplift has no rocks later than the Catahoula, direct structural evidence of possible later movements is impossible to secure. The only recourse is physiographic study based on accurate topographic maps, and no part of the Sabine uplift has been topographically mapped.

PHYSIOGRAPHY

The physiographic history of the iron ore area begins after the formation of the northeast Texas syncline and the Sabine uplift and the development by erosion of a gulfward-sloping peneplain. Because the top of the Sabine uplift consisted of easily eroded Wilcox Eocene sands and clays the surface of the peneplain developed upon it lay lower than that of the syncline to the northwest. The gulfward slope of the peneplain appears to have been increased by a southeastward tilting which began an epoch of subaerial deposition during which streams built up a depositional plain on top of the formerly denudational peneplain surface. Although the time of peneplanation cannot be dated definitely by available fossil evidence, various lines of reasoning indicate that it is probably near the end of the Tertiary.

The epoch of deposition which followed the peneplanation was caused by uplift which began in the mountain areas of Colorado, New Mexico, and Trans-Pecos Texas about the beginning of the Pliocene and continued to a much later time, although we do not know when it ended. Deposits began first to form just east of the mountain flanks and with the course of time the streams gradually shifted them farther east and southeast. Tilting of the country towards the Gulf of Mexico occurred along with the uplift of the mountains. Increase of slope increased the work of the streams and uplift increased rain and snowfall. It may have taken nearly all the Pliocene for the stream deposits to reach as far as the iron ore district.

The streams which built up the depositional plain flowed towards the Gulf much as they do today. After the depositional plain of the relatively thin "Lafayette" deposits was built up, the streams began to cut down their courses and have continued their erosional activities up to the present time. It is probable that the present epoch of erosion had a number of causes. One would be a renewal of the gulfward tilting. Another would be a decrease in the amount of detritus carried by the streams as the interior region was eroded to lower levels, bringing about a change from depositing to eroding streams. Another would be a possible change in the climate.

The present streams which developed with courses consequent to the gulfward slope of the "Lafayette" depositional plain after cutting through those deposits became superposed on the underlying Eocene strata. This accounts for the fact that the various Cypress creeks and the middle course of Sabine River have southeastward courses across the northeast Texas syncline and the Sabine uplift. The upper Sabine River drainage—above the trough of the syncline—has become adjusted more to structural conditions, flowing down a very broad and gently warped southeast-plunging syncline. The headwaters part of Neches River flows southwards in the trough of the southern part of the northeast Texas syncline but it appears probable that the river shifted down the dip of the hard laminated iron ore until it reached the synclinal trough and then more deeply intrenched its valley. The headwaters of Angelina River have been adjusted so as to flow for the most part in areas of the loose, easily eroded Queen City sands.

During the epoch of erosion following the formation of the syncline, ground waters were able to alter some of the original iron minerals to limonite and possibly to enrich the deposits in and near the synclinal trough by downward movements of iron salts in solutions from higher marginal areas subject to weathering and solution. The same processes would continue during the epoch when the "Lafayette" depositional plain was being formed. The rejuvenation and dissection of the area by the stream-cutting of post-"Lafayette" time have destroyed something like four-fifths of the formerly existing iron deposits.

The main secondary concentration of the iron ore occurred in the time between the deposition of the iron silicates and perhaps carbonate and sulphide and the end of the "Lafayette" epoch. Iron ore gravels are found in abundance in the "Lafayette" and later sediments. The renewal of erosive processes after the deposition of the "Lafayette" and the consequent entrenchment of the drainage courses have dissected the formerly probably continuous blankets of iron ore into ridges, hills, buttes and mesas, which owe their relief to the resistant capping of iron ore. After the streams had cut down through the iron ore capping and underlying compact greensand, wherever the latter was present, they reached unconsolidated sands which were easily washed away. These sands carried water which flowed out to the surface as springs and seeps along the valleys excavated in the sands. The outflow from the springs carried sand down into the stream courses, its removal depriving the overlying material of its support, undermining or sapping it and causing it to cave off in blocks and settle down the slopes. This brought about gradual recession of the cliff walls and widening of the valleys. Most of the stream valleys except in their gorge and gully-like headwaters have greatly broadened on the sand horizons. On the whole, only something like one-fifth to one-tenth of the probably original iron ore sheets are now present. The conglomerate ores of the region, for the most part worthless because they have a high content of sand and foreign gravel, are lodged on the valley walls and bottom, the present day springs and seeps from the iron silicate or iron ore rocks carrying sufficient iron in solution to form upon precipitation a cement or binder for the sands, chert and other pebbles, and pebbles and boulders of the detrital iron ore. The "foreign" pebbles in the iron conglomerate come mainly from the "Lafayette" deposits, remnants of which still cap some of the highlands and are still being carried by streams down into the valleys. The iron ore gravels produce a good grade of road material, as demonstrated in the improved roads of Cherokee County.

The stream dissection of the area, in the more recent geologic past and present, has brought about a new epoch of iron concentration, particularly in the valleys at and near the surface at lower levels than the old deposits. Probably considerable concentration of iron is now taking place at the base of the sands on the surfaces of underlying impervious clays, the iron being derived from solutions which penetrate the sands.

PROBLEMS OF THE ORIGIN AND CONCENTRATION OF THE IRON DEPOSITS

The iron ores of northeast Texas have the superficial appearance of being a very simple occurrence, but in reality they present a number of puzzling and as yet unsolved problems. Some of these are the source of the iron, the true nature of the iron silicate minerals, the conditions under which the original minerals were deposited, the role which has been exerted by secondary alteration, concentration, and enrichment, and the influences upon the last by the physiographic and geologic history since the original deposits were made.

Source of the iron.—It has been supposed heretofore that the source of the Claiborne iron was the older Navarro Cretaceous and Upper Cambrian iron silicates. It now appears that very little Upper Cambrian sediments were exposed to erosion in the interior of North America during Eocene times. If the Navarro deposits were the source of the Claiborne iron there would still remain the necessity of finding a source for the Navarro iron. A little further analysis of the problem indicates that quantitatively the Navarro falls far short of meeting the requirements. Even if the Navarro iron-bearing strata are conceded the maximum possible area of outcrop during Claiborne times, we are little better off. It is probable that the Midway sediments then covered a considerable portion of the nearer Gulf part of present exposed Navarro and while the Navarro outcrops undoubtedly then extended farther inland than now there is doubt that the Navarro ever extended farther inland than the Gulf Coastal Plain province, the interior limit of which may be taken as approximately the present line of contact between the Comanche and Gulf series of the Cretaceous.

What really must be explained is a long period of deposition of iron minerals which began with the Navarro Cretaceous and lasted until the end of the Eocene. The Claiborne of the Gulf Coastal Plain all the way from Georgia far into Mexico contains great quantities of iron minerals. This is true also of the Midway and the Jackson stages and likewise the Wilcox wherever the latter is marine. Also, deep borings demonstrate the presence of the iron minerals far down the dip gulfward from the present exposures. The Cretaceous of New Jersey and the British Isles contain large quantities of iron silicates. There is considerable iron silicate also in the Eocene of California. In the northeast Texas iron ore district, where four-fifths or more of the original deposits have been destroyed by erosion, there were originally perhaps 5 billion tons or more of iron ore and almost certainly 2½ billion tons or more of metallic iron.

Van Hise, Leith, and other geologists have long since concluded that the original source of the iron ores of the American part of the Lake Superior region was from older basic eruptive rocks especially those of the Keewatin. Collins and Quirke more recently have presented even more cogent evidence that the ores of the Canadian Michipicoten district are derivatives of the Keewatin eruptive processes. Similarly, the source of the abundant glauconites in the Upper Cambrian of the central United States would appear to be from the Keewatin, from the Huronian iron deposits derived originally from the Keewatin, and from the later and extensive basic igneous rocks of the Keeweenawan. The Ozark and central Texas pre-Cambrian contributed to some extent in the formation of the Upper Cambrian glauconite.

The Mesozoic eruptions of basic igneous rocks are the greatest known since the pre-Cambrian. In three areas alone—eastern South America, South Africa, and peninsular India—these eruptions covered to great thicknesses a territory of a million square miles. The Deccan basaltic plateau of India is still mantled with a great accumulation of residual lateritic iron ores, and in South Africa and South America very extensive red residual soils rich in iron have been derived by weathering from the basic igneous rocks. Basic eruptives of Cretaceous age are known in the Gulf Coastal Plain from the state of Mississippi to the Mexican border, in the Greater Antilles, where they are the source of the large reserves of residual iron ore in eastern Cuba, and in northern South America. Another important area of these basic eruptives is in the island of New Caledonia in the western Pacific. Of earlier Mesozoic age are the extensive basalts and diabases in the Newark Upper Triassic of the eastern United States and the basic igneous rocks of the Coast Ranges of California, Oregon, and Washington. Basic eruptions occurred during Triassic time in Nevada and in Sonora, Mexico, and during Middle Cretaceous times in Lower California. Of less definite date but possibly at least in part of Cretaceous and Eocene times are the extensive basic eruptions in Arabia, Somaliland, and Abyssinia, and perhaps farther south in the Rift Valley province of East Africa. The vast region of basalt lava extending from northern Ireland and the Western Isles of Scotland through the Faröe Islands to Iceland is considered by British geologists to have been formed by eruptions which began at least in the Eocene; in fact, all the definitely dated eruptives are apparently Eocene.

The iron was derived from the basic igneous rocks by action of sea water on them, through the processes of subaerial weathering and decomposition, and from the hot solutions emanating from the eruptives. Probably the largest quantity of iron known in any single region in the world outside of the Lake Superior region occurs in the mid-Mesozoic deposits of the Lower and Middle Jurassic extending from far east in Germany through Luxemburg, Belgium, northern France, and southern England as far as the island of Skye, off the northwest coast of Scotland. It was deposited in the form of silicate, and in many ways these deposits resemble those of the Claiborne Eocene of northeast Texas.

No doubt the eruptions from Triassic to Eocene times must have contributed large quantities of iron and silica to the ocean. The difficulty is to keep the iron in solution in ocean water. The iron in solution in the present ocean is apparently no more soluble than the calcium carbonate, and the amount of Fe_2O_3 now in solution amounts to only three-ten-thousandths of 1 per cent of the total volume. However, the present ocean may be far from being saturated with iron and at any event the widespread occurrence of the iron silicate glauconite on the ocean floor and of iron compounds in all marine sediments demonstrates that the ocean water receives and carries in the aggregate a large quantity of iron. Possibly also a large part of the iron as well as of the silica is carried in suspension as colloids.

There was probably a gradual accumulation of iron and silica in the ocean as Mesozoic time progressed. Much was taken out to form the Jurassic iron deposits of Europe, and thereafter their deposition on a large scale took place in various areas during the Cretaceous and Eocene. The time involved is enormous; immense quantities of iron and silica must have emanated from hot solutions coming from the eruptions and from the subsequent leaching of the eruptive rocks.

Conditions for deposition (precipitation) appear to have been more favorable in the shallower waters of partly landlocked embayments. One such was the Upper Cretaceous and Eocene Gulf of Mexico. Currents would bring in the substances from the more open ocean. Such environmental conditions would include mechanical washing and aeration by waves conducive to the formation of oolites from suspended colloids, abundance of reducing organisms, including bacteria, in the shallower waters and mixture of waters of different composition from land areas which brought in colloidally suspended clays (silicates, silica, and alumina), which go out of suspension and settle on the bottom when fresher waters from the land become mixed with those of the sea. A greater relative amount of evaporation occurring in areas of very shallow water than in areas of deeper water probably would cause greater amount of iron and silica precipitates.

Very probably some reconcentration of iron took place during the Claiborne. The northeast Texas syncline may have begun its development in the Middle Cretaceous. It appears to have subsided during the Wilcox, and the alternation of very shallow marine and land-laid sediments indicates at least oscillatory conditions during the Claiborne. During all these times and later there was occurring a progressive though secular recession of the Gulf shores southwards, caused likely by the simultaneous operations of three processes, namely (1) filling in of the marginal area by sediments; (2) progressive deepening with the progress of time of the central Gulf area; and (3) an uptilting of the marginal area during continued subsidence in the direction of the central Gulf area. Some or all of these brought the marginal Navarro formation out of water and subjected it to erosion before and during the Eocene. Older Eocene marginal deposits underwent the same history during times when later Eocene deposits were forming in a progressively restricted Gulf. Hence, Navarro and earlier Eocene deposits contributed iron to the later Eocene both as detritus and in solution. The maximum amount of iron silicates and perhaps other iron minerals was laid down during the Weches stage, and the subsequent depression of the syncline and the deposition of a protective cover both in the syncline and the monoclinal area farther south preserved a part of the iron formation from subsequent erosion.

There is some likelihood that another process aided deposition of the iron formation. This is mass action, which apparently operates as a cause of many primary deposits, forms concretions in many cases, and accounts in part for many secondary enrichments. The operative principle is that the presence of a substance causes concentration around it or adhesion to it of more of the same substance provided this substance chances to be in solution or suspended in a colloid and can be precipitated. Hence, detrital iron silicate or other iron minerals brought into the area may be a cause of precipitation of more iron minerals if the necessary substances happen to be present already in solution or suspension.

The formation of iron silicate has been emphasized because research in the Jurassic iron formations of Europe and those of pre-Cambrian age around Lake Superior and the widespread glauconite in deposits of many ages now indicate strongly that the primary or original iron mineral is silicate and that in these deposits the carbonate is secondary. It should not be forgotten, however, that in some other marine iron formations, such as the Clinton iron ore of the Appalachian province, iron oxide, partly at least of oolitic structure, is considered to be primary. There is a possibility, as we shall see, that much at least of the laminated type of northeast Texas ore may be primary and non-marine.

Lindgren[29] describes the sedimentary processes in the following extract:

> Regarding the marine ores, it is certain that glauconite and allied iron silicates are deposited in the sea and that under special reducing conditions siderite and iron disulphide may also form. . . . Whether limonite is ever formed in sea-water is more doubtful for the salt solutions have a strong dehydrating effect. Many of the "marine" limonites are products of oxidation of siderite and iron silicates. The marine iron ores are all shallow water deposits and the frequent oolitic structure is in part at least due to accompanying action of waves and currents. . . . In the origin of oolites, colloid precipitates play an important part. The calcite oolites are believed to have been precipitated in successive layers of calcium carbonate gel, which almost instantly was converted into fibrous calcite. Likewise the concentric structure of siderite and chamosite passed through a gel stage accompanied by the adsorption of phosphorous.

[29]Lindgren, Waldemar, Mineral Deposits, pp. 313–314, 3rd ed., McGraw-Hill Book Company, New York, 1928.

Sidney Paige[30] states that the Upper Cambrian glauconite in the Llano uplift of central Texas "probably owes its origin to the decomposition of abundant potassium feldspar with iron in solution, the subsequent synthesis of the several elements being probably aided by organic matter."[31]

The processes and conditions under which iron minerals are derived directly from eruptives have been considered by Collins and Quirke on pages 31–32 and 73–78 of their "Michipicoten Iron Ranges," Memoir 147, Geological Survey of Canada, 1926. Unfortunately these discussions are too long to be quoted here.

Under ordinary processes of weathering, iron is carried into solution by the following agents: (1) carbon dioxide from the air and decomposing organisms; (2) sulphuric acid from the weathering of pyrites; and (3) organic acids derived from decomposing vegetable matter. Where air is excluded, ferric oxide is reduced to the ferrous state and forms soluble double salts with ammonia and humic acid.

IRON SILICATES

The most abundant and widespread mineral of the Claiborne iron formations is iron silicate, which generally has been considered to be glauconite. However, it is darker and duller green than glauconite, it is oolitic, which glauconite is not, and it does not have the composition of glauconite, lacking especially its rather uniform potassium content. The various sedimentary iron chlorites or silicates have approximately the following composition:

	Glauconite *Per cent*	Chamosite *Per cent*	Thuringite *Per cent*	Greenalite *Per cent*
SiO_2	48	25	23	30
Al_2O_3	7	17	17	
Fe_2O_3	24	6	15	35
FeO	2	39	33	26
CaO	1			
MgO	3	3		
K_2O	7			
H_2O	8	10	11	9

[30]Paige, Sidney, Description of the Llano and Burnet quadrangles: U. S. Geol. Surv., Geol. Atlas, Llano-Burnet folio (No. 183), field edition, p. 45, 1912.

[31]A discussion of the iron silicates and their origin, with additional references to the literature, may be found in W. H. Twenhofel and others, Treatise on Sedimentation, 2d edition, pp. 452–460, Williams and Wilkins Company, Baltimore, Md., 1932.

Most at least of the northeast Texas iron silicate deposits contain more or less clay, sand, or limestone as impurities. The following table includes analyses of ores selected from Schoch's[32] "Chemical analyses of Texas rocks and minerals" as being nearest in percentage of silica to glauconite.

Analysis No.	46	47	48	50	56	67	68	76
SiO_2	45.70	49.47	47.00	43.10	45.80	47.10	48.30	37.50
Al_2O_3	18.09	24.29	9.78	13.66		4.66	8.81	8.89
Fe_2O_3	4.00	6.76	21.42	27.54	38.90	21.43		
FeO	4.71					2.60	34.19	32.33
CaO	8.70	1.48	7.58	1.07	2.20	6.83	2.06	2.39
MgO	2.00		2.30	4.76	2.23	2.81	1.44	0.80
K_2O	4.57	0.13	1.27	0.56	1.14	2.62	2.48	0.99
Na_2O	1.20	2.17	4.65	3.66	6.00	3.52	1.58	0.65
H_2O	11.00	14.17	N.D.	N.D.	4.21	7.00		13.02
P_2O_5	0.12	0.072	0.56	0.17	Tr.	Tr.	Tr.	0.12

None of the above fills the requirements otherwise than in an approximation to silica content of glauconite. The potash percentage in none is sufficiently high, and all contain considerable Na_2O, which does not occur in glauconite but which indicates that potash probably has not been leached out to any considerable extent, because Na_2O ordinarily is leached more readily than K_2O.

Probably the purest iron silicates occur in the beds with the most limestone because such are free from most clay and sand detritus. Three analyses of this kind, recalculated after carbonates are deducted, give the following results:[33]

Analysis No.	45	53	63
SiO_2	44.10	36.13	20.67
Al_2O_3	11.19	20.44	23.94
Fe_2O_3	8.40		25.50
FeO	21.81	30.99	9.32
CaO	1.0		
MgO	3.0		1.11
K_2O	5.11		Tr.
Na_2O	Tr.		3.85
H_2O	3.30	11.93	16.34
P_2O_5	Tr.	0.50	0.26
SO_3		0.84	0.13
$CaCO_3$	33.80	19.33	24.25
Na_2CO_3		1.13	
K_2CO_3		0.51	
$FeCO_3$		10.92	

[32] Schoch, E. P., Univ. Texas Bull. 1814, p. 170, 1918.

[33] *Idem.*

Analysis No. 45 is of a substance nearest to glauconite, although with too much iron and alumina. The other two are not glauconite for they lack potash and magnesia and have far too low percentages of silica.

In the next table[34] are those analyses with percentages of silica more nearly like those of chamosite, thuringite, or greenalite. It is noteworthy that in some of these the percentages of iron are fully as high as in the Cleveland Hills Jurassic iron ores of Yorkshire, from which England at present derives the largest part of its domestic iron ore:

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[34] *Idem.*

Analysis No.	40	41	42	43	45	51	53	57	58	59	69	70	73	74	75
SiO_2	20.95	25.95	30.85	32.00	29.40	30.00	24.68	30.50	32.00	20.10	25.20	30.40	32.10	20.70	26.30
Al_2O_3	16.28	11.20	16.87	20.66	7.46	14.11	13.96	24.27					15.54	7.40	27.81
Fe_2O_3					5.60	25.09		4.93					12.71	44.62	29.59
	47.62	45.25	36.83	34.94			27.22	4.93	54.60	32.34	58.68	52.60			
FeO					14.54			14.49					20.39		
CaO	1.81	5.20	0.60	0.66	20.00	10.80	10.83	2.31	5.18	11.20	2.96	2.46	1.98	1.31	0.90
MgO	1.46	1.40	1.46	1.14	2.88	3.46		3.66	11.20	Tr.	4.68	3.92	5.20	0.57	1.60
K_2O	0.93	0.13	1.72	0.66	3.41	0.80	0.35	2.05	Tr.	2.66	4.15	2.28	3.62	Tr.	3.29
Na_2O	3.94	2.12	3.44	3.77	Tr.	4.41	0.66	Tr.	Tr.	1.09	4.04	4.97	2.37	0.42	4.66
H_2O	5.65	5.85	6.00	6.35	2.20	N.D.	8.15	17.00		13.50	3.11	3.11	5.20	16.10	5.00
P_2O_5	None	0.38	0.41	0.42	Tr.	0.44	0.34	0.41	0.83	0.75	Tr.	Tr.	Tr.	4.79	0.22
Mn										1.55					

Index to Localities[35]

The following list gives localities for analyses in the 3 tables appearing on pages 459 and 461. For explanation of abbreviations used in this list, see footnote 14, page 341.

Analysis
No.

40. Cherokee County. Greensand (Eocene Tertiary). From Mount Selman. T. G. S. A. R. I., p. 94.

41, 42, 43. Not given.

45. Houston County. Greensand (Eocene Tertiary). From K. Jones' well on N. C. Hodges Headright. T. G. S. A. R. III, p. 29.

46. Houston County. Greensand (Eocene Tertiary). From Alabama Bluff on Trinity River. T. G. S. A. R. III, p. 29.

47. Houston County. Greensand (Eocene Tertiary). Marked "Greensand Clay," Hurricane Bayou. T. G. S. A. R. III, p. 29.

48. Houston County. Greensand (Eocene Tertiary). From L. Williams Headright. T. G. S. A. R. III, p. 29.

50. Houston County. Greensand (Eocene Tertiary). From D. McLeany's Headright. T. G. S. A. R. III, p. 29.

51. Houston County. Greensand (Eocene Tertiary). From Robbins' well on Leonard Williams' Headright. T. G. S. A. R. III, p. 29.

53. Leon County. Greensand from J. W. Barton, Oakwood, Texas. Analyzed 1915 by J. E. S. B. A. 2717.

56. Marion County. Greensand marl (Eocene Tertiary) in a bluff overlooking Big Cypress in Jefferson. T. G. S. A. R. II, p. 114 (1890).

57. Nacogdoches County. Greensand marl (Eocene Tertiary). One-fourth mile southeast of Nacogdoches. Analyzed by J. H. H. T. G. S. A. R. II, p. 277.

58. Nacogdoches County. Same as No. 57, but roasted. Analyzed by J. H. H. T. G. S. A. R. II, p. 277.

59. Nacogdoches County. Altered calcareous greensand marl (Eocene Tertiary). From Simpson's Hill, 4 miles northwest of Melrose. Analyzed by J. H. H. T. G. S. A. R. II, p. 277.

63. Nacogdoches County. Altered calcareous greensand marl, bed 2 feet, 8 miles northwest of Nacogdoches. Analyzed by J. H. H. T. G. S. A. R. II, p. 277.

67. Nacogdoches County. Calcareous greensand marl (Eocene Tertiary), 1 mile southwest of Cherino. Analyzed by L. E. Magnenat. T. G. S. A. R. II, p. 277.

68. Panola County. Greensand (Eocene Tertiary), from Alex Carter on the Wm. McKnight Headright. T. G. S. A. R. II, p. 232 (1890).

69. Rusk County. Greensand marl (Eocene Tertiary), upper bed 20 feet, Stevens' Branch, Sulphur Springs. Analyzed by J. H. H. T. G. S. A. R. II, p. 259.

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[35]Schoch, E. P., *op. cit.*, pp. 20-22.

70. Rusk County. Greensand marl (Eocene Tertiary), from bed 6 feet under pyrite, Stevens' Branch, Sulphur Springs. Analyzed by J. H. H. T. G. S. A. R. II, p. 259. (1890).
73. Rusk County. Greensand marl (Eocene Tertiary), lower bed 3 feet exposed, Stevens' Branch, Sulphur Springs. Analyzed by L. E. M. T. G. S. A. R. II, p. 259. (1890).
74. Rusk County. Altered greensand marl, or fossiliferous orange loam, Sulphur Springs. Analyzed by L. E. Magnenat. T. G. S. A. R. II, p. 259. (1890).
75. Rusk County. Altered greensand marl, 1 mile east of L. D. Stevens' house, near Sulphur Springs. Analyzed by L. E. Magnenat. T. G. S. A. R. II, p. 259. (1890).
76. San Augustine County. Greensand (Eocene Tertiary), near San Augustine. Sample from W. L. Belahoussaye, Beaumont. Analyzed by J. E. S. B. A. 2741.

Some of these samples, especially part of those analysis of which is given in the last table, are not free from the suspicion that there has been leaching of silica and secondary addition of iron. A number of them have such a small content of potash that they would not appear to have any notable content of glauconite. On the whole it appears most likely that most of the iron formation is a mixture of varying proportions of chamosite, thuringite, and perhaps greenalite, with perhaps some content of glauconite present locally, or, perhaps, the potash content may occur in clayey impurities. The range in depth of water in the present oceans for glauconite deposition is between 269 and 10,500 feet which is possibly or probably a greater depth than that which prevailed in northeast Texas at the time of deposition of the Claiborne sediments.

W. J. Mead has formed greenalite in the laboratory through the reaction of ferrous salts and water glass (sodium silicate) in saline solution.[36] The equations expressing the reactions are: $FeSO_4 + Na_2O\ 3\ SiO_3 = FeO.3\ SiO_2 + Na_2SO_4$ and $FeCl_2 + Na_2SiO_3 = FeSiO_3 + 2\ NaCl$.

Sodium silicate is one of the common products of weathering, and it is possible that the northeast Texas iron silicates are formed in this manner, which may account for the Na_2O in the analyses above.

Hallimond[37] thinks that along a shallow muddy shore the waters were charged with colloid clay material; as the ferrous iron

[36]Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Surv., Mon. 52, pp. 521-522, 1911.

[37]Hallimond, A. F., Iron ores: bedded ores of England and Wales. Petrography and chemistry: Special Reports on the Mineral Resources of Great Britain, vol. 29, Geol. Surv. Great Britain, Memoir, 139 pp., 1925.

increases in the detritus or through organic action, the solubility product of chamosite will be reached and chamosite precipitated. The calculated composition of the Cleveland Hills iron ore of Yorkshire is:

	Per cent
$CaSO_4$	2.84
$CaCO_3$	7.13
$MgCO_3$	7.88
$MnCO_3$	0.68
$FeCO_3$	34.70
Chamosite	34.24

PROBLEMS OF ALTERATION AND SECONDARY ENRICHMENT

Dr. W. B. Phillips[38] combined analyses of ores from four northeast Texas counties as shown in the following quotation.

In studying these analyses it was decided to divide them into four groups—for example, from 40 to 45, 45 to 50, 50 to 55, and 55 to 60 per cent of iron. All ores containing less than 40 per cent of iron are disregarded. The time may come when such low-grade material may be used, through processes of crushing, jigging, etc., but we need not concern ourselves with this now. We distinguish, then, four classes of these ores:

Medium, containing from 40 to 45 per cent of iron.
Good, containing from 45 to 50 per cent of iron.
Very good, containing from 50 to 55 per cent of iron.
Extra, containing from 55 to 60 per cent of iron.

It is probably the case that most of the so-called brown ores (and, with the exception of some carbonate ore, all of the east Texas iron ores are of this character) used in this country carry about 45 per cent of iron. It is an exception to the general rule when such ores carry as much as 50 per cent of iron, save when they are calcined, and this practice is not common. Such ores go direct from the washers to the stockhouse, a very small proportion being calcined or otherwise improved.

Cass County, 47 analyses

	Per cent
Medium	29.8
Good	23.4
Very good	23.4
Extra	23.4

[38]Phillips. W. B., Iron and steel making in Texas: Iron Age, vol. 89, pp. 141–143, 1912. Reprinted in Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee counties, Texas: U. S. Geol. Surv., Bull. 620, pp. 95–97, 1915.

Average Composition

	Medium	Good	Very good	Extra	Average, all analyses
Metallic iron (Fe)	42.43	48.23	52.33	57.58	48.64
Silica (SiO_2)	18.26	11.85	5.19	3.94	10.64
Alumina (Al_2O_3)	11.33	7.85	5.21	5.21	7.65
Phosphorus (P)	.108	.147	.107	.052	.103
Sulphur (S)	.098	.133	.124	.065	.104

One sample, not included in this classification, contained iron, 60.44; silica, 3.50; phosphorus, 0.038; sulphur, 0.220.

Marion County, 65 analyses

	Per cent
Medium	4.6
Good	15.4
Very good	9.3
Extra	70.7

Average Composition

	Medium	Good	Very good	Extra	Average, all analyses
Metallic iron (Fe)	43.18	46.69	53.80	57.43	54.91
Silica (SiO_2)	19.55	13.10	4.90	3.27	5.18
Alumina (Al_2O_3)	7.41	8.40	8.33	2.69	4.30
Phosphorus (P)	Trace	.093	.070	.084	.073
Sulphur (S)	.030	.380	.156	.100	.067

In two of the good ores the silica was 26.43 per cent. In one the alumina was 19.96 per cent and maximum sulphur was 0.735. In one sample of the good ore the alumina was 16.50 per cent; the maximum sulphur was 0.304. The maximum phosphorus in one sample of the extra ore was 0.22 and the maximum sulphur was 0.22. This county has not only the highest average of extra ore, but the highest general average in metallic iron—*viz.*, 54.91 per cent.

Morris County, 10 analyses

	Per cent
Very good	50
Extra	50

Average Composition

	Very good	Extra	Average, all analyses
Metallic iron (Fe)	52.82	56.85	54.83
Silica (SiO_2)	7.76	5.55	6.85
Alumina (Al_2O_3)	4.99	3.39	4.19
Phosphorus (P)	.132	.113	.125
Sulphur (S)	.007	.011	.009

In the very good ores the maximum silica was 13.10, maximum alumina 6.84, and the maximum phosphorus 0.209. Considering that no analyses with less than 51 per cent of iron are quoted from this county, it would appear that the best average of ore is from Morris County, although Marion County has the highest percentage of ore with more than 55 per cent of iron.

Cherokee County, 10 analyses

	Per cent
Medium	40
Good	60

Average Composition

	Medium	Good	Average, all analyses
Metallic iron (Fe)	42.34	46.15	44.64
Silica (SiO_2)	22.62	17.19	19.01
Alumina (Al_2O_3)	11.47	10.35	10.94
Phosphorus (P)	.156	.140	.146
Sulphur (S)	.227	.029	.117

In the medium ores the maximum silica was 25.13, the maximum alumina 23.41, the maximum phosphorus 0.315, and the maximum sulphur 0.607. In the good ores alumina was determined in only one sample. The maximum silica was 20.36 and the maximum phosphorus 0.284. . . .

The differences between the composition of the Weches greensands and the average iron ore of Cherokee County are shown in the next table. The last column gives the composition of the average iron ore, and the next to the last column gives the composition of a greensand near Dialville, sufficiently indurated to be used for a building stone. This Dialville greensand is noteworthy in having one-fifth the alumina and considerably less silica than the average iron ore. The other columns give analyses of various greensands.

SiO_2	20.95	25.95	30.85	32.00	14.40	19.01
Al_2O_3	16.28	11.20	16.87	20.86	2.07	10.94
CaO	1.81	5.20	0.60	0.66	3.05	
MgO	1.46	1.40	1.46	1.14	5.00	
P_2O_5		0.38	0.41	0.42	0.54	
P						0.146
S						0.117
Na_2O	3.94	2.12	3.44	3.77		Tr.
K_2O	0.93	0.13	1.72	0.66	4.61	
FeO					25.96	
	4762	45.25	36.83	34.94		69.79
Fe_2O_3					30.27	
H_2O	5.65	5.85	6.00	6.35	14.00	

Perhaps the most remarkable difference between the greensands and the iron ore is in the alumina content. The average percentage of alumina in 21 of the greensands is 15.21, the range being from 4.66 to 27.81 per cent. In iron ore from Marion and Morris counties the alumina content based on 75 analyses averages only 4.2 to 4.3 per cent; in Cass County ores the alumina content based on 47 analyses averages only 7.65 per cent; in laminated ores from Cherokee County based on 10 analyses the average alumina rises to 10.94 per cent. Alumina is very hard to dissolve and to keep in solution. If the oxide iron ores of the region were formed by oxidation of original silicate, carbonate, or sulphide minerals or from any one of these or mixtures of these, and the enrichment from iron formation to workable ore was brought about solely by leaching out of the other non-ferrous constituents of the original iron formation, one logically would expect that the alumina percentage would increase with that of the iron. Pure iron carbonate (siderite) contains 48.2 per cent of iron. Pure iron disulphide (pyrite and marcasite) has 46.6 per cent of iron. Because northeast Texas ores contain considerable percentages of silica and alumina, it is not possible to derive them from the sole oxidation of carbonate or disulphide for their iron content is too high. It becomes even more impossible to derive them from iron silicate greensands, which have less iron content than carbonate or disulphide. Therefore, it appears that one is forced to assume either that part of the original constituents was iron oxide, or that iron has been added in the process of secondary enrichment, or else that both are true.

Secondary enrichment involves a circulation of waters, not only to bring in the added iron but to remove in solution the potash, soda, lime, magnesia, and part of the silica. There are conditions under which a carbonic acid solution of iron carbonate, meeting an oxidizing solution, precipitates the iron as ferric hydroxide and at the same time dissolves silica.

Evidence favoring possibly original deposition of iron oxide is perhaps best in the Rusk district of Cherokee County. The laminated and "curly," "buff crumbly" ores have more the appearance of being original "bog iron" oxide deposits than secondary. The layer of irregular-surfaced white clay lying between the laminated ore above and the top of the Weches greensand below looks like a weathered or leached soil which had been eroded somewhat before the accumulation of the overlying iron ore. New road cuts in Cherokee County prove a markedly irregular lower contact of the ore. If the iron ore here was derived from the alteration and enrichment of the underlying greensand it should pass downwards gradually through a zone of intermixed greensand and iron ore into unaltered greensand.

Another fact which appears significant is that the workable iron ore beds appear to be overlain commonly by ordinary sands; the change from iron silicate formation below into ordinary sands above implies at least an abrupt change in nature of sediments, which suggests unconformities or diastems. Kennedy states that the lower level nodular or concretionary ores all occur in positions unconformable with underlying strata. It may be found that the workable oxide ores are fresh water "bog iron" deposits and the silicate ores marine deposits. This might be true even where oxide layers are interbedded with silicates, or perhaps in those cases oxidation and secondary enrichment have taken place.

The northeast Texas oxide ores are all limonites and, if original precipitates, it is doubtful whether they are marine because salt solutions such as sea water have a strong dehydrating effect. This is also in accordance with the ore beds being overlain by sand of the ordinary variety without marine fossils.

The Weches greensand in the Brazos and Colorado river basins is apparently as rich in iron silicates as the strata farther northeast, but, although some limonite occurs at the top and within the member, there are no workable iron ores. This fact suggests that there were conditions in the northeast Texas syncline and adjacent to it on the southern margin of the Sabine uplift which favored formation of workable iron ore. The synclinal area during the marine Claiborne (Reklaw and Weches) epochs may be considered to have been a shallow strait, which became filled up to Gulf level at the end of the two marine epochs. During the Queen City sand epoch and to a greater extent at the beginning of the Sparta sand epoch, iron oxides may have been deposited in fresh water bogs and marshes. The iron may have been derived from solution of the marginal iron silicate formations, iron salts in solution having been carried down into the low marshy synclinal area and there precipitated, partly as concretionary siderite but mainly as laminated, "curly" ("buff crumbly") and concretionary limonite. In the case of the Cherokee County laminated ore a greater percentage of clay and sand would appear to have been transported into the area where iron ore was forming. A small amount of sinking of the synclinal trough, not enough to bring in again Gulf waters but elevating somewhat the marginal Weches and Reklaw to bring them within the zone of weathering, would afford a source for the iron.

The following quotation from Lindgren[39] discusses the processes of limonite deposition:

Precipitation is effected in bicarbonate solutions by the escape of carbon dioxide in the air or through its absorption by plant cells. The ferrous carbonate is easily oxidized to ferric hydroxides. In the presence of much organic matter ferrous carbonate remains in the precipitate.

From ferrous sulphate solution iron is precipitated as limonite by oxidation and hydrolysis, or by reaction with calcium carbonate solution, in which case siderite and gypsum will result, the former oxidizing to limonite, or the iron may be precipitated by ammonium humate, always present in swamp waters, or finally by soluble calcium phosphate, in which case vivianite or other iron phosphates results. Less commonly the iron is precipitated as pyrite by alkaline sulphides or hydrogen sulphide.

From soluble humates iron is also precipitated by organisms including iron bacteria, which take up these humates as well as ferrous carbonate, and coat their cell walls with the segregated limonite, but regarding the real importance of this process we have few data.

In these, as so many other surface reactions, the ferric hydroxides are probably precipitated as colloidal complexes of indefinite composition, of "gels," which in time tend to change to crystalline bodies. Much of the ferric hydroxide is doubtless transported for considerable distances in colloid form. Five species of ferric hydroxide have been recognized. Arranged by increasing water they are:

Turgite	$2\ Fe_2O_3.H_2O$	94.6 per cent FeO
Goethite	$2\ Fe_2O_3.2\ H_2O$	89.9 per cent FeO
Limonite	$2\ Fe_2O_3.3\ H_2O$	85.5 per cent FeO
Xanthosiderite	$2\ Fe_2O_3.4\ H_2O$	81.6 per cent FeO
Limnite	$2\ Fe_2O_3.6\ H_2O$	74.7 per cent FeO

Goethite is crystalline, the writer having found it in a fissure vein cutting the Ellenburger group in northeastern San Saba County, Texas. Turgite is red and may be mistaken for hematite. It is probably present in northeast Texas where it forms the coloring matter for the red soils in the Eocene territory. It probably is the coloring matter of the red soils of the Llano uplift.

The oxidation of glauconite in surface weathering is well shown in the Upper Cambrian strata of the Llano uplift. These strata are more porous and soluble than the iron silicate formations of northeast Texas; they consist of sands, gravels and limestone. The sands and gravels contain interstitial glauconite. These strata weather on the surface to rusty-brown, reddish-brown, or yellow oxides. Concretions of very dark brown limonite cement a large content of sand.

[39]Lindgren, Waldemar, *op. cit.*, pp. 294-295.

Even on bright green, fresh exposures the rock when struck with the hammer emits an abundant red powder, the color of which probably is due to turgite. The sandy soils derived from these rocks are in places quite red from iron oxide but in other fairly extensive areas are light buff. Where of the latter color, probably most of their original iron oxide content has been leached out. In other places there are deep red, somewhat sandy, clay soils, which if freed from their sand content, might make very acceptable red iron ocher.

Rapid oxidation of the greensands takes place in recent road cuts in northeast Texas. The nodular concretionary ores of northeast Texas appear to be associated commonly with sands. These ores may be syngenetic but since the associated sediments have never been consolidated they may be at least partly epigenetic. Where the concretions are in sands, it would seem that abundant sand grains would be included in them, as in the case of the concretions of the Llano uplift, but their silica content is not high, which means that if they are secondary (epigenetic) the sand must have dissolved at least in part as the concretions formed. The writer has observed considerable iron silicate in the cores of some of the iron carbonate concretions, which means either that iron carbonate in them is secondary or, possibly, simultaneous formation of both silicate and carbonate.

The nodular concretionary ores of the northern area do not appear to be underlain commonly by impervious clays or greensands. It is different in the southern laminated ore area where the main ore body is at the top of the Weches greensand. This greensand forms an impervious zone which descending waters cannot penetrate readily. As heretofore stated, it is difficult to account for the laminated structure of this ore if it be a secondary alteration and concentration; if secondary, it would appear that a concretionary structure would be the more probable.

It is certainly true that the synclinal structure, with plunge to the southward, and the occurrence of the workable ores either at the bottom of sands or within the sands strongly suggest secondary concentration and enrichment by downward-moving waters bringing in iron either from strata directly above or from higher flanking parts of the syncline. Where the ores are in the midst of the sands, original syngenetic limonite, or perhaps carbonate, concretions might grow secondarily by attracting more iron to them through mass action.

Burchard's description of the deposits on the Surratt tract, Cass County, already quoted, shows silica sand at the base upon which rests a 4-foot layer of clay. About 5 feet of concretionary and nodular iron carbonate in green iron silicate sand and greenish clay rests upon the 4-foot clay bed. The next highest strata are 35 feet or more of the oxidized zone of fragments and layers of limonite scattered throughout yellowish to reddish iron silicate sand and clay and sandy clay. The following table[40] gives in the first column analyses of nearly pure cleaned carbonate ore, in the second column an average of 22 analyses of nodular and concretionary limonite, and in the third column an average of 5 analyses of laminated limonite, all from Cass County:

	Per cent	*Per cent*	*Per cent*
Silica (SiO_2)	1.10	10.96	20.25
Alumina (Al_2O_3)	1.02	3.51	12.91
Lime (CaO)	.16		
Phosphorus (P)	.05	.118	.149
Sulphur (S)	.05	.124	.132
Loss on ignition (mostly combined water)	1.20	9.62	12.25
Carbon dioxide (CO_2)	36.54		
Manganese (Mn)	.10		
Titanium dioxide (TiO_2)	.04		
Metallic iron (Fe)	46.44	40.61	37.41

The carbonate ore is low in silica and alumina. The concretionary hydrous oxide ore contains less than half as much silica and alumina as does the laminated hydrous oxide. These analyses suggest that the carbonate ore may be primary, although associated with greensand, and that the oxide ores may be secondary, partly derived from oxidation of silicates and partly enriched by addition of iron subsequent to deposition. During secondary action some at least of the concretionary ore may have passed through the carbonate stage or else have contained a certain amount of primary carbonate.

PRODUCTION AND RESERVES OF IRON

The world's production of iron ore rose from 125,000,000 metric tons in 1906 to 200,000,000 metric tons in 1929. The world produced about 98,500,000 tons of pig iron in 1929, but the production fell to 80,647,000 tons in 1930. The United States produces between 36 and 37 per cent of the world's iron ore. The United States production of iron ore in metric tons in 1929 was 74,199,815. France

[40]Burchard, E. F., *op. cit.*, p. 86.

ranked second with 50,731,100, Great Britain third with 13,427,943, Sweden fourth with 11,467,551, Luxemburg fifth with 7,571,206, Russia sixth with 7,100,000, Spain seventh with 6,546,648, and Germany eighth with 6,191,232 tons. Russia rose to fourth place in 1930 with 10,148,500 tons, since when this country probably has made further advances. The strategic control of iron and steel rests with the United States and four countries of northern Europe—France, Great Britain, Sweden, and Russia. Other than the countries named and their foreign possessions no country produced as much as 2,000,000 tons of iron ore in 1929. Certain other countries, however, have important potential iron resources. These include Brazil, which alone has one-fourth of the remaining reserves of high grade ore, Chile, and China (including Manchuria). In 1929 two countries alone, United States and France (including her North African possessions), produced more than five-eighths of the world's iron ore.

In the production of pig iron the lead of the United States is more important because this country now utilizes ores richest in iron. In 1929 the United States produced 43,297,937 metric tons of pig iron, Germany was second with about 15,345,000 tons, France third with 10,362,000 tons, Great Britain fourth with 7,701,200 tons, Belgium fifth with 4,040,530 tons, Russia sixth (but rising to fifth place in 1930) with 4,018,700 tons, Luxemburg seventh with 2,906,093 tons, and Czechoslovakia eighth with 1,644,515 tons. Sweden produced only 523,829 tons of pig iron and Spain 752,618 tons. Aside from Sweden, where some very high grade iron and steel are made in the electric furnace from hydroelectric power and from charcoal fuel, the control of the world's iron smelting by countries having coking coal is paramount. Although France produced in 1929 more than 8 times as much iron ore as Germany, the latter produced 1½ times as much pig iron as the former.

The United States would not be able to continue the 1929 rate of production of iron ore for more than a generation. At the 1929 rate the high grade reserves of the Lake Superior region would have been exhausted in between 12 and 15 years. Lake Superior produces about 85 per cent of the United States total and has already produced more than 1½ billion tons of iron ore. Leith estimates that the Lake Superior reserves "now known promise a further life of about 20 years at the present rate of production, after which there will be a falling off due to the beginning of exhaustion of the Mesabi range of Minnesota, which has been the principal producer." The sale of steel is presumed to be at present one of our best business barometers; it is, therefore, interesting to note that about 46,000,000 tons of iron ore were shipped from the state of Minnesota in 1929, the peak year, and only 2,287,000 tons were shipped from that state in 1932.

Fortunately there are other reasons besides lack of ores why the United States and the world cannot continue for very long the 1929 rate of iron ore production. The most important is lack of demand. The market has been glutted, perhaps even supersaturated. It has been stated, upon good authority, that more metals have been produced during the twentieth century than in all previous time. If one is disposed to question this statement, he will find it certainly true that during the last half century more than half the total world all-time metal production has been attained. It is fortunate for humanity that production of metals does not mean their complete consumption. As production increases, the increasing supply means also an increase in the amount of metals which can be used over again, that is, the supply of "scrap" metals increases likewise. This serves to decrease constantly the demand for newly produced metals. Something else, however, is necessary in order to conserve our metal supply. This is the prevention of waste brought about by oxidation and corrosion. This is being consummated rapidly by the use of non-rusting and non-corrosive alloys and by other methods of recovery of metals already used. New substitutes are, and must be, constantly developed. One example is the constantly increasing use of aluminum and aluminum alloys as substitutes for iron and steel and copper. Herein the metal magnesium is becoming important for aluminum alloys, such alloys having among other advantages that of less weight.

Something happened in the 15 years preceding the end of 1929, the effects of which although becoming increasingly apparent cannot be realized sufficiently until some time in the future. This is the over-industrialization of the world during that period, or, at least, an over-production leading to a saturation or a super-saturation of demand, a supply beyond the purchasing power, as purchasing power is now distributed. The needs are yet very great but the needs cannot be satisfied so long as the present great inequalities exist in purchasing power. Such industrially backward and poor populations as still exist in Africa, Asia, and South America—and the same applies only to a lesser degree to the majority of the population of Europe and North America as well—do not have as yet the purchasing power to satisfy their needs.

The industrialized nations at present have not only glutted their domestic and foreign markets but have exported machinery and other products which have enabled other nations to industrialize to more or less extent. The effect has been great increase in competition. No nation has, nor can have, a monopoly very long in scientific and technical skill and discovery. This is aptly shown in the steel industry. The United States now leads in steel production, but modern processes in steel making were invented in England and improvements in them have been developed in virtually every steelmaking country.

Foreign and domestic reserves.—The estimation of foreign iron ore reserves is very difficult. Fully one-half or three-fourths of the earth has not been sufficiently explored. In the continents best known, Europe and North America, many deposits exist which do not outcrop. Some of them will be found eventually by magnetic or other geophysical methods or by accident. Also, low-grade deposits not now profitably workable may become so ultimately if sufficient need develops. Even today in many parts of Africa and in countries like India and China considerable native forge or charcoal iron is produced from scattered deposits too poor to be worked in North America or Europe. Previous to about 1850 the population of India and China, more than half the world's total, derived its iron supply very largely from such sources.

The iron ore reserves of the state of Minas Geraes, in Brazil, are of exceptionally high-grade hematite. They can be mined cheaply and require a relatively short distance haul down grade to the first-class deepwater harbor of Victoria. Brazil has an abundance of hydroelectric power but little coking coal, although the latter can be supplied from European and other fields at relatively cheap oceanic transport rates. The Minas Geraes reserves are estimated to be 5,710,000,000 tons. In other parts of South America there are large reserves notably in Chile, more especially near the oceanic port of Coquimbo, and apparently also in the Guiana Highlands of southeastern Venezuela, reasonably close to water transportation on Orinoco River.

Cuba's iron ore reserves are estimated to be about 1,900,000,000 tons containing 40 to 50 per cent iron, low in phosphorus. Mexico has a large mountain of iron ore, the Cerro Mercado, within the surburban district of the city of Durango. The coking coal of Mexico is in the northwestern part of the state of Coahuila. The center of the iron and steel industry of Mexico is the city of Monterrey.

South Africa has a large supply of iron ores which are mainly of sedimentary origin. Southern Rhodesia, eastern Transvaal, Zululand, southwest Africa, Natal, and Griquatown West have important deposits. In the last named region are some nearly pure hematites with 65 per cent metallic iron, derived by secondary enrichment much as in the Lake Superior region. In the Bushveld region there are considerable bodies of magnetite which could readily be mined if they did not all carry high percentages of titanic acid. Considerable deposits of titaniferous magnetite are situated in Portuguese East Africa. North Africa has large iron ore reserves, of which those in the Rif of Morocco are perhaps most important and are close to oceanic transportation.

The potentialities of Asia are still unknown, especially those of the interior of the continent. India, China, Korea, Manchuria, and the Unfederated Malay States-Johore produced about 5,500.000 tons of iron ore in 1929. The Far East does not appear to possess truly great resources, but one might venture to predict that central Asia is likely to have a large aggregate tonnage.

In Great Britain the rich blackband clay ironstone and brown hematites of the Carboniferous strata are almost exhausted. The leading district of this country is now the Lower Jurassic bedded ores of the Cleveland Hills of Yorkshire and Dorsetshire, where 200,000,000 tons of estimated recoverable ore existed in 1918. This ore is suitable for basic steel making, the average phosphorus content being 0.47 of one per cent. Eighty per cent of the British ore averages only 27½ per cent of metallic iron. The production of Great Britain and Ireland was at its zenith in the period 1871–1884 when it averaged 16 to 17 millions tons of ore annually. Already Great Britain is importing most of her ore. The nearest source within the Empire is the Wabana ore of the Bell Island region, Newfoundland, where the reserves are estimated at 3,250,000,000 tons, perhaps the third largest now existing iron ore reserve. The Wabana ores are oolitic with 50 to 70 per cent hematite, 15 to 25 per cent chamosite, 0 to 50 per cent siderite, 0 to 1 per cent calcite, and 1 to 10 per cent quartz. They are high in phosphorus.

Next to Brazil the largest known reserves are in Alsace-Lorraine and Luxemburg, where the total tonnage is over 5 billion. These have a low percentage of iron, from 31 to 40, and a high percentage of phosphorus, from 1.6 to 1.8. The lime averages 5 to 12 per cent and the silica from 7 to 20 per cent. These ores are utilized by the Thomas basic process, the slag being sold for fertilizer. The French, German, Belgian, and Luxemburg blast furnaces in 1927 produced 36 per cent of the world's pig iron. Sweden has some very high-grade reserves. Kiruna has a proved reserve of 740,000,000 tons, and the total workable deposit may run over 1 billion or even to 2½ billion tons. Gellivore, a short distance south of Kiruna, has large and important reserves. Most of the Swedish iron has been smelted with charcoal and is famous for its low sulphur and phosphorus content. Both the great deposits mentioned above are extremely high grade. They average 68 per cent iron from the magnetite which, however, is high in apatite with a phosphorus content varying from 2 to 4 per cent. The Narbotten deposits of Sweden, which include Kiruna, are fifth in rank among the world's known reserves, Kiruna having the largest quantity of richest ore in any single deposit yet known.

Russia's production is mainly from South Russia (Kriwoj Rog especially) and from the Ural Mountains. Most of the iron ore of Oceania is in South Australia, which produced 943,000 tons in 1930.

The world reserves in iron ore considered to be profitably workable at present are about 30 billion tons, equivalent to 14 billion tons pig iron. Additional possible and potential ore reserves are perhaps 100 billion additional tons. Two-thirds of this is in the Western Hemisphere, mainly in Brazil, the United States, Newfoundland, and Cuba. Of the remaining one-third, France controls about half.

The total ore production of the world up to the end of 1910 is estimated at 3,750,000,000 tons or about 1,700,000,000 tons of pig iron. More than half of this was produced in the 25 years from 1885 to 1910. In the next decade, 1911 to 1920, about 660,000,000 tons of pig iron were produced, and for the decade 1921 to 1930 the production was 740,000,000 tons. Therefore, in the 20 years just previous to the end of 1930 the production of that interval was forty-five per cent of the world's production of pig iron for all time. In the first 30 years (1900–1930) of the twentieth century, five-eighths of the world's total of pig iron was produced.

The world's annual pig iron production from 1911 to 1930 in long tons was as follows:

Year	Amount
1911	63,343,000
1912	72,719,000
1913	77,893,000
1914	59,805,000
1915	63,271,000
1916	73,334,500
1917	71,739,000
1918	65,246,000
1919	51,184,000
1920	61,206,400
1921	36,368,300
1922	54,893,500
1923	69,984,300
1924	68,501,000
1925	76,916,000
1926	78,857,000
1927	86,775,000
1928	88,956,000
1929	98,414,000
1930	80,647,000
Total	1,401,050,000

Present workable iron ore reserves in the United States are about as follows:

Locality	Amount
Total Lake Superior district	2,000,000,000
Minnesota	1,200,000,000
Michigan	160,000,000
Birmingham district, Alabama-Tennessee	2,000,000,000
Texas	200,000,000
Utah (Iron Springs)	40,000,000
California	
Eagle Mountains (62–67 per cent iron, low phosphorus)	60,000,000

In addition there are the following deposits: the Iron Age and Minaret of California, the Hanover-Fierro and contact deposits east of Sierra Oscura in New Mexico, and the Hartsville hematite and the high titaniferous magnetite dike of Iron Mountain, Wyoming. Other deposits found in the Appalachian states include residual limonite, the Clinton bedded hematite, and the magnetites of Pennsylvania, New York, and New Jersey. Possibly total United States reserves are no more than 5½ billion tons, with less total iron content than the beds in the state of Minas Geraes in B.azil.

The more usual workable iron ore deposit is of the order of tens of millions of tons, deposits of a hundred million tons are uncommon, while those of 1 billion tons are quite rare, perhaps not over a dozen such being known.

ECONOMICS OF TEXAS IRON ORES

In the above estimates of reserves in the Lake Superior and Birmingham districts the figures given are perhaps unduly optimistic. The reserves of present commercial grade in the Lake Superior region appear to be limited to about 30 years at the present rate of production. E. F. Burchard estimates that the Birmingham district has a reserve of 1,431,500,000 gross tons of first-grade ore above a depth to 3500 to 4000 feet and in addition about 500,000,000 gross tons of possibly available second-grade ore.

The Lake Superior district has a vast reserve of ore in addition to the above estimates, having an iron content not far below that which is at present profitable. Moreover, the steel and iron corporations operating in that district have very large investments in surface and underground mining equipment, railroads, ore docks, steamships, coal fields, coal mines, limestone deposits, blast furnaces, and steel plants, and no doubt they will make every effort to make profitable these marginal ore reserves. The grade of Lake Superior ore is so far being rendered fairly constant and uniform by various methods of beneficiation, and some further technical improvements making possible the utilization of ores lower in grade than those now workable are predictable. It is possible that the handling of larger tonnages than ever in the past will reduce tonnage costs so low that some at least of the lower grade ores will be profitable, even if Minnesota taxes are not reduced.

The iron and steel industry of the Birmingham district began with surface ores easily worked by open-cut methods. Birmingham red ore must now be mined underground at greater expense, and it does not appear possible to increase production to anything like the amounts mined in the Lake Superior district; in fact, Burchard states that production can never be as rapid as in the open-pits of the Mesabi range of the Lake Superior district. Moreover, the Birmingham red ores are fairly low grade, averaging 37 per cent iron content. About 10 per cent of the Birmingham production is from brown limonite, averaging 50 per cent iron content, but this class of ore is not nearly so extensive as the red hematite. The Birmingham district has the advantages of low-cost water transportation by way of Black Warrior River to the Gulf of Mexico and of having the iron ore, limestone for flux, and coking coal for fuel all concentrated within the radius of a few miles, something which no other really large iron ore district on earth possesses. Some of the Birmingham ore, like some of the minette ore of Lorraine, has sufficient lime to be self-fluxing. Most Birmingham steel is made in open-hearth furnaces, much of the pig iron being used directly as hot metal in the open-hearth process.

Birmingham ores will remain a serious competitor of the Texas iron ores after the exhaustion of the Lake Superior reserves. Texas iron will continue to have other important competitors. These are Brazil, eastern Cuba, and the Wabana district of Newfoundland. The last two are situated practically at oceanic harbors, and the overland haul from the Brazilian deposits, which are higher grade ore than that of Texas, is very little more than from the Texas deposits. Nine-tenths of the iron ore of the United States is made into pig iron or steel in plants in the districts of the lower Great Lakes and Atlantic seaboard where there is abundant coke and flux, the greater part of the domestic market and good facilities for export. Newfoundland, Cuban, and Brazilian ores can reach present iron and steel centers in the main with low cost oceanic transportation. It remains to be seen whether the three foreign countries will be willing to permit their raw ores to be exported to the United States; they may compel finished iron and steel to be made within their own territory for the benefit of their own capital and labor. If these foreign sources of ore should be shut out, the beginning of the development of northeast Texas ores is not more than 25 to 50 years distant.

It is not altogether the lack of nearby coke and limestone which has prevented the development of a Texas iron and steel industry.

The iron and steel industry of Pueblo, Colorado, like that of the northeastern United States, transports its iron ore to where coke and limestone are situated. Ore from the Pueblo works comes from the Hartville district of central-eastern Wyoming and the Hanover-Fierro district of southwestern New Mexico. A blast furnace at Provo, Utah, uses ore from the Iron Springs district of southwestern Utah. There is a long, expensive rail haul over mountain grades for ore from the Utah and New Mexico mines; for instance, 700 miles from Fierro to Pueblo. Pueblo has an iron and steel industry because it is in the heart of a vast interior region to which overland transportation of heavy commodities is highly expensive.

The Texas iron ore is nearer coking coal—in Oklahoma and Arkansas—than are the iron ores which are hauled to Pueblo. Abundant limestone for flux is available on the way from the Texas ore to the coke. However, any iron or steel plant whether on the Gulf coast, in the ore area, or in the coking coal territory would be within the range of effective competition of existing plants.

Heretofore the main tendency in industry has been towards centralization, at the expense of the consumer. Now, cost of transportation is beginning to exert an increasing burden on over-centralized industry, which has also other disadvantages, as has been set forth in the section on coal and lignite. Although some distance from coke and flux, the northeast Texas iron ores are higher grade and can be mined much cheaper than those of Birmingham, their greatest competitor, because situated at least distance. If coke can be supplanted by oil, gas, or electricity, northeast Texas will be able to produce iron and steel as cheaply as or cheaper than Birmingham.

As matters stand at present, the highly centralized and controlled iron and steel industry already possessed of the market of Texas and the adjacent area is not apt to make the additional expenditure of establishing a plant in Texas, and with the market already controlled by very powerful interests no one else is likely to attempt to compete.

The present writer is, therefore, largely of the opinion of Dr. W. B. Phillips,[41] who wrote in 1912 as follows:

> Iron and steel works of the size to make profitable use of by-product ovens are not now needed in Texas or the Southwest. Instead, it seems to us that a

[41]Phillips, W. B., Iron and steel making in Texas: Iron Age, vol. 89, pp. 14–16, 141–143, 1912.

blast furnace plant producing 250 to 300 tons of pig iron a day, with a steel plant whose product would enter into the lighter finished forms, is much more to the point. The initial investment would be much less and the character of the product could be kept in closer touch with actual demands. The logical location for such a plant would be in east or northeast Texas, in close proximity to the ore fields and within reach of the coking coal of Oklahoma and Arkansas. . . . The nearer an iron furnace is to regular supplies of coke the better. . . . The most favorable outlook in Texas and the Southwest for the manufacture of iron and steel is in the direction of a blast furnace with auxiliary steel plant, not operated so much with reference to the demand for the heavier forms, such as structural shapes, plates or rails, as to the demand for cotton ties, wire fencing, wire nails, perforated metal, pipe and light steel castings. That such an enterprise would succeed here, under proper management, is, we think, well within the bounds of probability.

Had there been such a plant in Texas making tubular goods in operation during the last 20 years, it would not only have been profitable but would have saved the oil industry of Texas, Oklahoma, Arkansas, Louisiana, and New Mexico a large amount expended for rail transportation from the Great Lakes, Ohio, and the Pittsburgh district.

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THE IRON ORES OF EAST TEXAS[1]

EDWIN B. ECKEL AND PAUL E. M. PURCELL

INTRODUCTION

One of the projects undertaken by the United States Geological Survey during 1934 as a result of allotments from Public Works Administration funds was a study of the iron ores of east Texas. Only the more important results of the work are summarized in the following paragraphs, as a detailed report is in preparation.

Previous studies of the Texas iron ores by geologists of the Federal Survey have been essentially limited to a rapid reconnaissance of the northern part of the field in 1904 by E. C. Eckel[2] and a somewhat longer reconnaissance examination in 1914 by E. F. Burchard.[3] The field work during the 1934 season was sufficiently detailed to allow a rather definite limitation of the areas from which commercial production of iron ore can be expected, to permit a preliminary estimate of the available tonnage, and to yield many

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[1]Published by permission of the Director U. S. Geological Survey.

[2]Eckel, E. C., The iron ores of northeastern Texas. U. S. Geol. Surv. Bull. 260, pp. 348–354, 1905.

[3]Burchard, E. F., Iron ore in Cass, Marion, Morris, and Cherokee counties, Texas: U. S. Geol. Surv. Bull. 620, pp. 69–109, 1915.

data concerning the problems of origin and enrichment of the iron-ore deposits.

Field work began early in April and continued through November. J. R. Stone gave able assistance during the early part of the

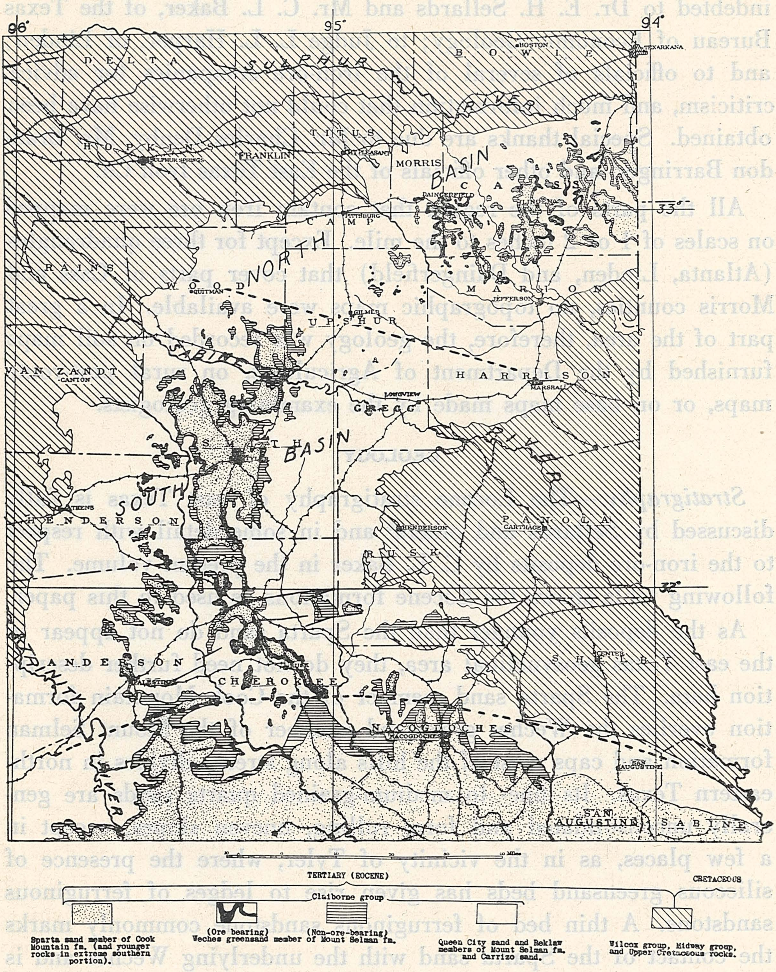

Fig. 24. Distribution of commercial iron ore in east Texas. Additional areas, particularly in Anderson and Henderson counties, may be considered as ore bearing only under very favorable conditions. From geologic map of Texas in preparation by U. S. Geological Survey in coöperation with Texas Bureau of Economic Geology, with additions by the writers.

season, and E. C. Williams, whose services as rodman were of much value, continued through the greater part of the season. Mr. Purcell joined the party June 28 and remained in the field until the end of November. E. F. Burchard made three visits to the field and gave much helpful advice. The writers are also especially indebted to Dr. E. H. Sellards and Mr. C. L. Baker, of the Texas Bureau of Economic Geology; to Judge L. L. Harper, of Linden; and to officials of several of the iron-ore companies for advice, criticism, and much information that could not otherwise have been obtained. Special thanks are due to Mr. Charles Denby, Mr. Brandon Barringer, and other officials of the East Texas Iron Co.

All the parts of the region that contain iron ore were mapped on scales of 1 or 2 inches to the mile. Except for three quadrangles (Atlanta, Linden, and Daingerfield) that cover parts of Cass and Morris counties, no topographic maps were available. In a great part of the area, therefore, the geology was recorded on soil maps furnished by the Department of Agriculture, on rural post-route maps, or on base maps made by the examining geologists.

GEOLOGY

Stratigraphy.—The Eocene stratigraphy of east Texas is fully discussed by Sellards and others[4] and in some detail with respect to the iron-ore deposits by C. L. Baker in the present volume. The following table shows the Eocene formations as used in this paper.

As the deposits younger than the Sparta sand do not appear in the east Texas geosynclinal area, they do not need further description here. The Sparta sand member of the Cook Mountain formation overlies the Weches greensand member of the Mount Selman formation and caps most of the hills along stream divides in northeastern Texas. Its fine- to medium-grained quartz sands are generally unconsolidated and form rolling, uneven slopes, except in a few places, as in the vicinity of Tyler, where the presence of siliceous greensand beds has given rise to ledges of ferruginous sandstone. A thin bed of ferruginous sandstone commonly marks the contact of the Sparta sand with the underlying Weches and is an easily recognized key bed. South of the area under discussion the Sparta is as much as 300 feet thick, but within the geosyncline

[4]Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, vol. 1, Stratigraphy: Univ. Texas Bull. 3232, 1007 pp., 1932 [1933].

Table 1.—Outline of Eocene stratigraphy in northwestern Texas

System	Series	Subdivisions			Thickness (feet)	Lithology
Tertiary	Eocene	Jackson group.			(?)	Sand, clay, and volcanic tuff. Shallow-water, marine, and beach deposits.
Tertiary	Eocene	Claiborne group	Yegua formation.		600–1000	Sand, clay, and lignite, with lentils of carbonaceous clay. Continental deposits.
Tertiary	Eocene	Claiborne group	Cook Mountain formation	Upper part.	125–450	Dark clay with some sandy shale, siliceous sand, and greensand; ferruginous and calcareous concretions. Largely of marine origin.
Tertiary	Eocene	Claiborne group	Cook Mountain formation	Sparta sand.	230–300	Fine- to medium-grained gray to buff unconsolidated quartz sand, cross-bedded in places, with sandy clay and a little lignite in upper parts. One or more lentils of siliceous greensand. Continental deposits in large part.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Weches greensand member	2–100	Greensand, with varying proportions of glauconitic oolites, clay, and siliceous sand. Cross-bedded in places. Characterized by abundance of iron ore in weathered parts. Marine deposits.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Queen City sand Member.	65–400	Light-gray medium-grained cross-bedded unconsolidated quartz sand and sandy clay, with lentils of lignite, bentonite, and greensand. Abundant pebbles of brown iron ore at one or more horizons. Largely of continental origin.
Tertiary	Eocene	Claiborne group	Mount Selman formation	Reklaw member.	80–180	Glauconitic clay and sand, with some impure lignite. Low-grade limonitic iron ore in weathered parts. Marine deposits.
Tertiary	Eocene	Claiborne group	Carrizo sand.		10–60	Medium-grained quartz sand with some sandy clay. Continental in large part.
Tertiary	Eocene	Unconformity				
Tertiary	Eocene	Wilcox group.			500–1000	Sandy clay, sand, and lignite, with some ferruginous and calcareous concretions. Of continental, littoral, and marine origin.
Tertiary	Eocene	Midway group.			300–900	Silty clay and greensand, with calcareous lentils and concretions. Largely of marine origin.
Tertiary	Eocene	Unconformity				

only the lower beds remain, and the thickness ranges from almost nothing to a maximum of about 100 feet.

Nearly all of the commercial iron ore of eastern Texas is associated with the Weches member, which overlies the sand and clay of the Queen City sand member, unconformably at least in places, and is overlain by the Sparta sand. In a few places beds of glauconitic material occur in the Weches, but in general the greensand is a mixture of oolitic iron silicate, with varying proportions of clay and quartz sand. Lateral variations in character and composition are common, but in general there are two distinct facies of Weches sediments.

A zone that passes through the central parts of Harrison, Upshur, and Wood counties appears to mark the division between these facies. As it also marks a break in the trend of the east Texas geosyncline there seems to be some basis for subdivision of the area on both structural and stratigraphic grounds. For present purposes the name "North Basin" is proposed for that part of the east Texas geosyncline which lies north of this zone and "South Basin" for the southern part of the geosyncline.

The chief differences between the Weches greensand of the North and South Basins are summarized in the following table. The list of pr'mary characteristics is followed by one noting the secondary features, such as type of iron ore or behavior on weathering, which are directly related to the original characters.

Table 2.—Comparison of North and South Basin facies of Weches greensand

North Basin	South Basin
Primary features	
1. No marine fossils visible	1. Marine fossils abundant
2. Plant remains widespread	2. No plant remains visible
3. Abrupt variations in thickness common	3. Variations in thickness very gradual
4. Average thickness 25 feet or less	4. Average thickness 40 to 50 feet
5. Typically composed of interbedded oolitic glauconitic sand, quartz sand, and clay	5. Typically composed of glauconitic clays of uniform composition. Very little quartz sand
6. Glauconitic grains commonly coarse	6. Glauconitic grains commonly fine
7. Evidence of unconformity with Queen City sand definite in places	7. Definite evidence of unconformity with Queen City sand lacking
8. Strong cross-bedding not uncommon	8. Cross-bedding lacking
9. Several areas of nondeposition	9. No areas of nondeposition

Secondary features

10. Iron ore distributed throughout the section	10. Iron ore confined almost exclusively to top of member
11. Ore concretionary and nodular	11. Ore laminated or massive
12. Ore erratically distributed areally	12. Ore uniformly distributed areally
13. Siderite always present in depth	13. Very little siderite present
14. Weathered surface light brownish red to yellowish brown	14. Weathered surface greenish brown to dark red
15. Soils rough and gravelly	15. Soils commonly soft except for debris from top ore bed
16. Topography rugged, with steep slopes	16. Topography less rugged, with more gentle slopes

As shown on Figure 24, the boundary between the North and South Basins extends northwestward from the northernmost point of Gregg County in a direction parallel to the course of Sabine River. There is apparently an intermediate zone in which some gradation takes place, the boundary not being as sharp as the single line on the map indicates. However, the two facies are so distinct that it is nearly always possible to state with some certainty whether a given outcrop of ore or greensand is of the North Basin or South Basin type. The distinction between the facies has much practical interest, as the physical and mineralogical characters of the original greensands have had profound effects on the quantity and character of the resulting iron ores. Furthermore, the recognition of these facies should be of considerable value to petroleum geologists, who generally consider the top of the Weches greensand member one of the best marker horizons in east Texas. In the monoclinal area south of the east Texas geosyncline the Weches greensand is not unlike that of the South Basin facies except that it appears to contain an even higher proportion of clay and a greater abundance of fossils.

The Weches greensands were laid down in a long, narrow trough, which corresponded closely to the present east Texas geosyncline, and probably never extended much farther than the present outcrop indicates. The greensand thins out rapidly and becomes much more sandy on its approach to the Sabine uplift, in eastern Cass and Marion counties, indicating an approach to shore-line conditions there. Evidence as to the position of the western shore line is more obscure, but in Van Zandt County and western Smith County the greensands are coarser and more sandy along the western flank of the present outcrop, where they approach the North Basin type in many respects, and indicate that the shore line was probably not very far west of the present western limit of the Weches greensand. In the North Basin shallower waters and more oscillatory conditions must have prevailed than in a large part of the South Basin. This would account for all the differences in primary features of the two facies of the Weches greensand member.

A detailed study of the mineralogical character of the greensands is not yet complete, but, in connection with the points raised by C. L. Baker in his interesting discussion of this subject, it may be worthwhile to note the results of some recent work done in the United States Geolog'cal Survey laboratories. The chemical analyses of the greensands made by Survey chemists on samples representing the freshest and purest material obtainable without hand picking of the glauconitic grains and on one carefully hand-picked sample are very similar to those recorded by Baker and show very little potash. Most of the Survey analyses and those noted by Baker show considerable proportions of ferrous carbonate, which indicates that the formation of siderite was already in progress. If potash is extracted early in the weathering process it would naturally not be present in samples containing any considerable proportions of iron carbonate. Several analyses of greensands from the Weches member as recorded by the Dumble Survey[5] show as much as 4 per cent of K_2O and suggest that truly fresh samples might be found to contain more potash than that commonly recorded. Clarence S. Ross, who examined some of the sands microscopically, states that they do not have the optical characteristics of glauconite. He further states, however, that Dr. P. F. Kerr, of Columbia University, examined the sands by X-ray methods and found them to give figures identical with those of glauconite. It seems possible that a mineral of the glauconite group does not necessarily contain potash, but much further study is necessary before definite conclusions on this perplexing problem can be reached.

The Queen City sand member of the Mount Selman formation underlies the Weches greensand. It consists of a thick series of unconsolidated medium-grained light-gray to reddish cross-bedded quartz sands interbedded with sandy clays and containing a few lentils of lignite and bentonite. The member is largely of continental

[5]Walker, J. B., Description of counties, *in* Reports on the iron-ore district of east Texas: Texas Geol. Surv., 2d Ann. Rept., pp. 259, 277, 1891.

origin, though it contains one or more lenticular beds of greensand, which is always indicative of marine conditions. The Queen City sand covers a greater area in the east Texas geosyncline than any other stratigraphic unit and forms a gently rolling, mature type of topography. Crusts and concretions of limonite occur in places throughout but are most common near the top of the member, where their presence is probably due to the infiltration of iron-bearing solutions from the overlying Weches beds. Water-worn pebbles of brown ore, which retain ghosts of oolitic structure, occur at several horizons, but nowhere is there sufficient ferruginous material to form workable iron ore.

The Reklaw member of the Mount Selman formation is composed of glauconitic clay and sand of marine origin. Its topographic expression is similar to that of the overlying Queen City but of somewhat less relief. Although limonite is widely distributed throughout the weathered parts of the Reklaw, apparently the proportion of glauconitic material in the clay and sand is everywhere too small to allow the formation of iron-ore deposits, such as are characteristic of the Weches greensand.

The Carrizo sand and the Wilcox and Midway groups all contain ferruginous concretions in places but not in large enough quantity to constitute ore.

Structural geology.—The geologic structure in east Texas has been fully discussed with reference to the iron ores by Baker in the present volume, and it is only necessary to note the basis on which the North and South Basins are here differentiated and to record some data on the relation of the Weches sediments to structure.

Through Cass, Marion, and Morris counties and northern Upshur County the trend of the east Texas geosyncline is southwestward, but this trend shifts abruptly to southward at the line that separates the North and South Basin facies of the Weches greensand. The dividing zone extends from the northern limit of the east Texas oil field northwestward through the Kelsey anticline, 6 miles west of Gilmer. North of the east Texas field wells drilled in the search for oil have shown the Woodbine sand to be several hundred feet lower than in the main producing area and have demonstrated a marked northerly dip in the subsurface structure. Previous studies of surface structure and drill records by Paul E. M. Purcell show that the structural axis of the Cretaceous rocks in the South Basin is parallel to and almost exactly under the synclinal axis of the Eocene beds. In the North Basin, however, the axis of the Eocene syncline is some miles east of that shown by the Cretaceous formations. In both series of beds a marked difference in lithologic characteristics in the two basins is apparent.

There is little direct relationship between the structure and the ore deposits, although the quantity, quality, and character of the iron ores depend largely on the character of the original Weches sediments. As these sedimentary characteristics are in part related to the structural conditions that prevailed during Weches time, it may be said that the iron ores are somewhat remotely related to the structure. Most of the structural features were in existence during Weches time. Along several faults the Weches greensand is much thicker on the downthrown side, indicating movement along the fault while the greensands were being deposited. In some places abrupt changes in thickness and character of the Weches along well-defined structural features indicates that the structural lows were also topographic lows at the time of Weches deposition. In general the formation is thinner and sandier on structural highs. This condition applies not only to the Weches greensand but to almost all the other Tertiary formations in east Texas.

IRON ORES

The limonitic ores of the North and South Basins are of different character. Full descriptions of the two types by other writers appear in the chapter by C. L. Baker. Nodules or concretions of brown ore, in many places coalesced to form layers or irregular beds, are characteristic of the North Basin ores, whereas the light-brown laminated and massive or "buff crumbly" ores are typically developed south of Sabine River. In a few places, notably near Cusseta, ore of the South Basin type has been found in the northern area, and here and there concretions of brown ore or carbonate occur in the lower parts of Weches exposures in the South Basin. In general, however, the line between the two basins separates the two types of ore just as sharply as it does the differences in primary character of the Weches greensand.

Origin of the ores.—Such features as the richness and continuity of the ores in depth or beneath heavy overburden depend directly on the mode of origin and thus make it one of the decisive factors in the estimation of available reserves of ore.

All evidence indicates that both the concretionary ores of the North Basin and the laminated ores of the South Basin were derived from the iron silicates of the Weches greensand by ordinary processes of weathering. Differences in the details of the iron enrichment process exist and are specially marked between the two chief types of ore, but that the greensand was the original source of iron for all the deposits can hardly be doubted.

Origin of the North Basin ores.—A generalized section through the ore deposits of the North Basin is given below:

Generalized section through ore deposits of the North Basin.

Top.	Thickness *Ft.*	*In.*
Unconsolidated quartz sand (Sparta)	1–20	
Thin hard ferruginous sandstone (basal Sparta)		1–6
Greensand, thoroughly oxidized, with nodules and ledges of brown ore. Much reddish and yellowish clay in places. Horizon of brown iron ore	5–20	
Greensand, partly oxidized, with nodules of siderite (iron carbonate) somewhat altered to brown ore. Transition zone		6–12
Greensand, nearly fresh, partly cemented by siderite and containing nodules or thin ledges of fresh siderite. Horizon of carbonate ore	3–10	
Greensand, fresh, unaltered	1–10	
Light-colored siliceous sand (Queen City).		

This section shows a progressive change downward from thoroughly oxidized greensand and brown iron ore near the surface, through an intermediate zone where iron carbonate appears, to fresh glauconitic greensand near the base of the Weches member. The degree of alteration varies in actual sections between the extremes represented by completely oxidized material and essentially unaltered greensand. This variation is apparently due in part to variations in composition of the original greensand, but in greater part to variations in the relation of the overburden of Sparta sand to local water-table conditions.

The thickest and richest ores commonly occur in relatively small outliers where the Weches member has been bared by erosion or retains only a very thin cover of Sparta sand. Next in importance are the narrow, thinly covered fingers or ridges that project from larger hills. In the large areas where the Weches is covered by 15 feet or more of sand good ore is seldom found at the outcrop and little or no ore is encountered in wells or drill holes.

As a general rule two of the chief horizons for shallow water wells on the uplands of east Texas occur at the top and base of the Weches greensand. If the Sparta sand is more than about 12 to 15 feet thick the wells encounter water at the top of the Weches member, but if the Weches occurs at the surface water is ordinarily found at the base of the greensand. The greensands are above the water table and subject to weathering only where the cover of Sparta sand is thin. Figure 25 illustrates the general relations between water-table

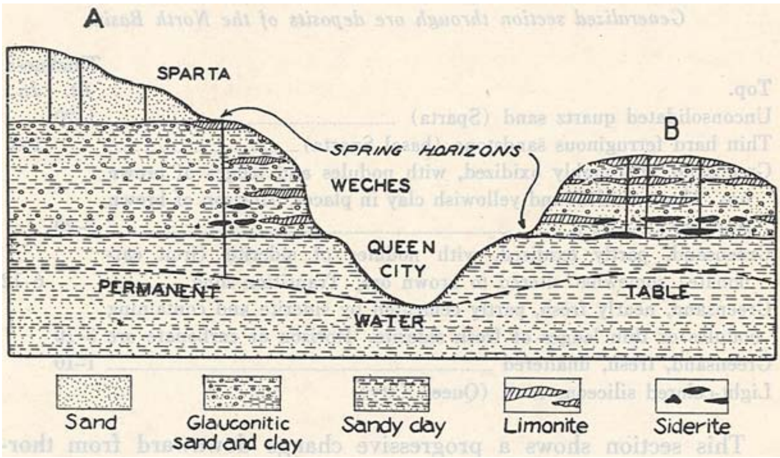

Fig. 25. Ideal section showing relation of ore deposits to local water-table conditions. At A, thick overburden and relatively large amount of clay in Weches greensand combine to form perched water table at top of Weches and to prevent formation of ore except at outcrop. At B, lack of overburden and sandy, permeable phase of Weches member combine to form perched water table at base of Weches and to allow formation of rich ore throughout hill. Heavy vertical lines denote water wells. Vertical scale, 1 inch = 50 feet.

conditions, extent of overburden, and character of ore deposits. It seems clear that rich accumulations of ore are seldom to be expected beneath a heavy cover.

The original composition of the greensand determines in part the character and amount of iron ore that results from weathering. If much clay or sand is included the ore will tend to be of lower grade on account of these impurities. But more important is the effect which these constituents have on the physical character of the beds and their permeability to ground water. If the beds contain so much clay as to be relatively impermeable or if there are alternations of sand and clay, the movement of ground water is greatly retarded, and rich ores cannot form except under special conditions. But if the greensand is sufficiently porous and permeable to allow free circulation of water, thick deposits of high-grade ore will usually be formed. The siderite is apparently deposited by circulating ground water, which dissolves iron from the glauconitic materials and transports it probably in large part as ferrous bicarbonate. The top of the ground-water level is commonly at the transition zone between the third and fifth members shown in Table 2, and it is only when the water is lowered temporarily by draft from wells or permanently by ditches or road cuts that the lower beds are accessible to view. Siderite occurs at the surface in a few places but only in stream beds or in other positions where there is sufficient water to prevent oxidation. It forms most abundantly near the top of the water table, where the water contains considerable carbon dioxide.

The flakes and fragments of carbonaceous material that are rather widely distributed through the Weches of the North Basin must exert some reducing effect and help serve to retard oxidation of the ferrous carbonate. The small amounts of pyrite that are sporadically distributed through the greensand undoubtedly play some part in the alteration process by yielding solutions of sulphuric acid and iron sulphate, but it is believed that the action of carbonated waters on the ferruginous silicates of the greensand is of prime importance in the formation of iron ore.

That there must be transportation and concentration of iron during the formation of ore from greensand seems obvious. The fresh greensand contains from one-third to one-half as much iron as the final product of alteration. The total volume of material seems to remain about constant during the alteration process, but the constituents are rearranged. Thus it is believed that much of the light-colored clay that occurs in the oxidized parts of the deposits is residual and due to the leaching of other constituents from the original greensands. In other words, the volume now occupied by iron ore and clay together was originally occupied by more or less homogeneous greensand.

The relation between the carbonate ore and the present water table makes it seem hardly probable that the carbonate could have been formed at the same time as the greensand, although of course small portions of it may be of primary origin.

Field evidence shows rather conclusively that most if not all of the brown ore has been formed by the oxidation and hydration of siderite. Many masses of siderite contain grains of unreplaced glauconitic material, and some of the brown ore, particularly that of lower grade, retains unmistakable ghosts and pseudomorphs of these original oolitic grains. In general form and distribution the bodies of carbonate and brown ore are closely similar, except that the siderite is everywhere more massive and contains less pore space than the brown ore. Many concretions with limonitic surfaces contain cores of carbonate that show septarian cracks, lined in places with limonitic material. A considerable shrinkage in volume during the change from carbonate to brown ore is to be expected on chemical grounds and is clearly proved by the field evidence. Much of the brown ore shows boxwork structure similar in all respects to the gossan of many nonferrous ore deposits that contain an abundance of carbonate minerals in the unoxidized zone.

When further erosion or other causes lower the water table sufficiently, the iron carbonate is exposed to the air and gradually alters to brown ore. Probably brown ore forms to the greatest extent in the belt of fluctuation of the water table, where seasonal variations in moisture are most marked and where plentiful supplies of oxygen are usually present.

The beds or ledges of ore are formed either during the carbonate stage by gradual accumulation of ferrous carbonate until the concretions coalesce or during the change to brown ore when water carrying more iron in solution cements the original concretions into a more or less solid mass. In a few places there is a secondary concentration of brown ore parallel to the present surface, and not uncommonly the surface ledge is of higher grade than the lower beds of ore. One such example is sketched in Figure 26, which shows the lenticular character of the lower beds and demonstrates one of the possible errors that may be made in the estimation of ore reserves if the thickness of ore in outcropping sections is measured. Such surface enrichments show that there has been considerable transportation and redeposition of iron since the present topography was developed. This condition is by no means universal, but it is of so great economic importance that it should be carefully looked for during the examination of all deposits.

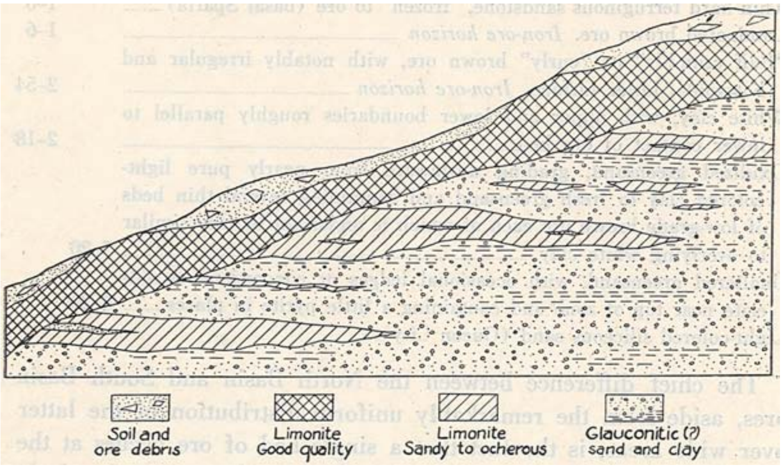

Fig. 26. Section along trench 5 miles southeast of Linden, Cass County. Shows secondary concentration of ore parallel to present surface, accompanied by increase in quality of the ore. This section also demonstrates the possible fallacy in basing calculations of ore reserves on thickness of ore at outcrop. Length of section, 10 feet.

That most of the brown ores contain about twice as much silica and alumina as the parent carbonate ores is in large part due to the fact that the removal of 30 to 40 per cent of carbon dioxide causes a relative increase in all other constituents. It is probable also that most of the few analyses of carbonate ore have been made on more carefully cleaned samples than those of the brown ores. Samples of limonitic ore as ordinarily taken for analysis contain much oxidized glauconitic and siliceous sand, which adheres to the surfaces of the ore fragments.

Origin of the South Basin ores.—The origin of the South Basin ores is merely a special case of the situation outlined above and is related to the fact that the Weches of the South Basin contains much more clay and is in general finer-textured than that farther north. A generalized section through the ore deposits of the South Basin is given below.

Generalized section through ore deposits of the South Basin.

Top.	Thickness Ft.	In.
Unconsolidated quartz sand (Sparta)	1–50	
Thin hard ferruginous sandstone, "frozen" to ore (basal Sparta)		1–6
Laminated brown ore. *Iron-ore horizon*		1–6
"Buff crumbly" or "curly" brown ore, with notably irregular and botryoidal lower surface. *Iron-ore horizon*		2–54
White clay, with upper and lower boundaries roughly parallel to lower contact of ore bed		2–18
Oxidized greensand, grading downward from nearly pure light-colored clay to fresh greensand and containing several thin beds of low-grade brown ore each of which is underlain by clay similar to overlying white clay	5–20	
Unaltered greensand, with occasional ledges or concretions of siderite near top of zone and containing a little pyrite in places	5–20	
Light-colored siliceous sand (Queen City).		

The chief difference between the North Basin and South Basin ores, aside from the remarkably uniform distribution of the latter over wide areas, is the fact that a single bed of ore occurs at the top of the Weches member in the South Basin. The few thin beds of limonitic material that occur in places below the top are sporadic in occurrence and generally too low in grade to be of interest as iron ore, but they have some importance in a study of origin.

The ledge of ore that marks the top of the Weches member shows variations in thickness within short distances, but ore occurs at this horizon over an area of several hundred square miles. Few of the outcrops seen in Smith, Henderson, Van Zandt, and northern Anderson and Cherokee counties failed to show some ore at this horizon. The persistence of ore at the outcrop is therefore not open to question. Intensive prospecting to prove the existence of ore beneath the whole surface of the plateaus of Cherokee County has never been attempted, but the weight of all evidence available at present leads to the conclusion that except under unusual conditions deposits of commercial iron ore are confined to a relatively narrow fringe about the edges of the hills. Many of the wells on the plateaus of Cherokee County encountered no ore or ferruginous sandstone, though they penetrated the upper parts of the Weches strata. Other wells encountered the top ore bed, but nearly all such wells are situated within 300 or 400 feet of the outcrop, and the overburden is relatively thin. Cuttings from several holes drilled by private seismograph parties were examined, and it was found that ore was penetrated only in the holes that were close to the outcrop of the ore bed. Many new road cuts show the ore to be continuous through the hills, but in all such cuts that were seen the hills were very small and overburden was thin or lacking. Mr. E. A. Wendlandt writes that his own experience and that of other geologists and geophysicists confirm the opinion that little or no ore is present at the top of the Weches in places where 10 to 15 feet or more of cover exists.

Water-table conditions in the South Basin are similar to those in the North Basin except that most of the hills are covered by so great a thickness of Sparta sand that the water table is more generally situated at the top of the Weches section. The finer texture of the South Basin Weches makes it relatively less permeable to the flow of ground water and is an important factor in establishing a perched water table near the top of the member.

Lateral and vertical variations in the character of the greensand are not as marked nor as abrupt as those in the North Basin. This uniformity in mineral and chemical composition has led to more uniformity in grade and character of the resulting iron ores.

The iron ore is everywhere more massive and contains less pore space than that of the North Basin. The upper 1 to 6 inches of the ore bed generally has fine open laminae, parallel to the bedding and lined with glossy black coatings. The "buff crumbly" ore beneath the laminated bed has a "curly" structure and resembles in some ways a mass of thoroughly coalesced concretions from which all but the last traces of concentric structure have been removed. In contrast with the top of the bed, which is nearly horizontal, the basal surface is extremely irregular on account of the botryoidal and rootlike protuberances that extend into the underlying clay. In a few places ghosts of spherical forms, probably the remains of glauconitic grains, have been found in both the laminated and the "buff crumbly" ores.

Vertical veins of brown ore are not uncommon in the vicinity of faults and extend downward from the main ore bed at least through the oxidized zone. These veins commonly have a central band of laminated ore, flanked on one or both walls by botryoidal masses of "buff crumbly" ore, similar in all respects to that of the main horizontal bed.

The white clay beneath the ore probably represents thoroughly leached glauconitic material. In places it retains ghosts of what were probably originally glauconitic oolites. The clay is usually somewhat thinner than the ore bed, but the thickness varies with that of the ore in general. The lower boundary of completely leached clay is roughly parallel to the base of the ore bed, but a downward gradation to less altered greensand is evident in most places. Similar zones of light-colored clay underlie the thin beds of limonite that appear below the top ledge, but such clay has not been observed where ore is absent.

It seems reasonable to suppose that the brown iron ores were derived from the Weches greensands by ordinary processes of weathering, in a manner similar to that which formed the North Basin ores. It is believed that iron is taken into solution by ground water and carried up to the top of the clayey greensand through capillary force, to be deposited there as brown ore, in part by oxidation and escape of carbon dioxide and in part by evaporation or transpiration of the water close to the surface. The fine, even texture of the glauconitic clay and sand presents ideal conditions for the rise of water by capillarity, though it tends to prevent downward migration of surface water. That the iron-bearing solutions did not penetrate the Sparta sands and deposit limonite there is explained by the relative coarseness and greater porosity of the quartz sand, which prevent capillary rise for more than a few inches at most.

If this theory of origin is correct, no ore should be expected under heavy overburden, for two reasons. First, the water that rises by capillarity would have no means of egress to the surface, and as it could not be removed the system would remain static, thus preventing a continued addition of iron from solution. Second, the capillary fringe, or the zone in which ground water rises by capillarity, is just above the water table, rather than beneath it. As has been already shown, the water table occurs at the top of the Weches section where the cover of Sparta sand is thick. Ore can therefore be formed only in areas close to the outcrop or where the overburden is light.

Whether all the ore has gone through the carbonate stage is unknown. The relatively greater density of the South Basin ore suggests that that ore did not, but it is difficult to explain the transportation of large quantities of iron by other means than bicarbonate solutions. Furthermore, coarse crystals of siderite have been observed in a few places embedded in massive brown ore.

The vertical veins of ore that occur in places were probably formed by downward-moving water that abstracted iron from nearby greensand and deposited it along fractures or faults. The general absence of white clay along the walls of the veins suggests that the iron was transported for some distance, but the similarity in structure of the veins to that of the horizontal ore beds indicates that they have been formed by the same or similar processes.

No explanation of the origin of the laminated ore above the "buff crumbly" ore is apparent, but it may be suggested that the laminated ore was deposited first, by solutions richer in iron than those which later formed the crumbly ore. Such a difference in composition might lead to the formation of somewhat different products. Again, the uppermost part of the Weches greensand may possibly have consisted of thin-bedded or laminated materials, which were replaced more or less differentially.

It is not possible that the iron has been derived from overlying ferruginous formations, for the very thick overlying Sparta contains but little ferruginous material except locally, and iron is probably seldom transported for long distances by ground water.

The possibility that the iron ores are of bog origin is suggested by some of the field relations, but careful study of all the evidence makes this explanation seem extremely doubtful. A plane surface sufficiently smooth to allow the formation of a thin film of bog ore from 2 inches to 3 or 4 feet thick over hundreds of square miles is possible but very improbable in a coastal-plain sedimentary series. The fact that the iron ore occurs only near the outcrop or under thin cover is of itself convincing evidence in opposition to the bog theory of origin.

The underlying white clay is suggestive of an old weathered surface, but its absence in areas where ore does not occur and its almost universal presence beneath all the layers of ore imply that it is closely related to the ore. The presence of ghosts of spherical forms in the iron ore and in the clay suggests though it does not prove that the iron ore was derived from oolitic greensand. The vertical veins of brown ore are so closely similar to the horizontal ore beds as to make it seem probable that they were formed by the same processes.

Age of the ores.—There is much evidence to show that most if not all the ores are of very recent origin. Unquestionably the formation of brown ores has been going on since early Tertiary time. Water-worn pebbles of limonitic material in the Queen City sand indicate that either just before or during Queen City time iron ores were being formed from older greensand. The formation of ores from the Weches greensand has probably gone on intermittently ever since the Weches first emerged, with breaks due to later submergences. But the ore was formed only on exposed areas and was eroded almost as fast as it was formed. The presence of carbonate and fresh greensand under heavy overburden or at the present water table indicates this history clearly. A perfect peneplain on a surface of the Weches greensand would over a long period of time have produced one of the world's largest and richest ore deposits, but such conditions did not exist. As soon as the cover of Sparta sand became thin enough to allow the formation of iron ore, the older ore at the outcrop was eroded, thus producing an ever fresh exposure of greensand to the action of the weather.

ORE RESERVES

Descriptions of most of the worth while ore deposits have been given by Burchard, and detailed sections through many of them are included by Baker in this volume. Figure 24 shows only the broadest regional relations between the deposits, but an attempt has been made to differentiate the areas of good ore. Detailed mapping during the present work made possible a rather definite limitation of the areas from which commercial production of ore can be expected under reasonably predictable conditions, although there are many large and promising areas where further prospecting is needed before accurate estimates of probable tonnage can be made. Phillips' map of reported iron deposits[6] was at hand during the field work, and every deposit shown thereon was seen by at least one member of the party. It was found that the mapping of many reported deposits was based on the presence of a few concretions of brown ore or carbonate. Some of these areas occur in Reklaw

[6]Phillips, W. B., Map of location of iron-ore deposits, blast furnaces, lignite mines in operation, and producing oil fields in east Texas: Univ. Texas, Bur Econ. Geology, Sept., 1912.

sediments, others in the Wilcox or the Queen City. Although iron minerals exist in all the counties and localities noted by Phillips and other investigators, commercial production can probably be obtained from only a small fraction of them. Even if the ore itself were of high grade and occurred in thicknesses sufficiently great to permit large-scale mining operations, such features as small areal extent, inaccessibility to existing lines of transportation, and excessive overburden would debar many of the reported deposits from further consideration.

In making an estimate of the probable tonnage reserves, the areas of ore-bearing land were scaled from field maps. Thickness of ore and cover and the ratio of ore to waste were determined on many tracts by measurement of hundreds of sections exposed in trenches, pits, or natural cuts. In other areas, particularly in the general vicinity of Hughes Springs, where little accurate information was available, the figures as to ore thickness were arrived at by analogy with the surface showings of better-known areas. It is believed that the figures for such areas are very conservative and that intensive prospecting will serve to increase the tonnage estimate rather than decrease it. No ore averaging less than 18 inches in thickness, exclusive of waste material that would be removed by ordinary washing methods, has been included in the estimate of probable ore. In several areas boulders and concretions of high-grade brown ore are distributed at or very close to the surface. Such boulders are frequently turned up by the plow in farming and are often accumulated in large piles in the fields. Though such areas could never be mined by large-scale machine methods, it seems probable that if a steady market for ore were established local farmers might supply considerable tonnages during the seasons when farm work is slack.

Information as to the specific gravity of ore in place is lacking for the most part. Experiment has shown that the Cherokee County ore, which is much more dense than that of the North Basin, weighs about 200 pounds to the cubic foot, corresponding to about 3890 long tons to the acre-foot. This figure has been used in the estimation of the South Basin ores. Estimates of the relative porosity of the North and South Basin ores, together with averages of the information furnished by several of the iron-ore companies that have made rather thorough studies of their ores, make it seem probable that the North Basin ores will weigh about 170 pounds to the cubic foot, corresponding to about 3250 long tons to the acre-foot.

The ratio of ore to waste, exclusive of overburden, ranges from about 1:5 to 1:1 in the North Basin, but in the South Basin, where the ore is confined to a single bed, probably no concentration other than removal of the overburden and the hard sandstone cap rock will be necessary. No material that would yield washed ore containing less than an average of 43 per cent of metallic iron has been considered in making estimates of tonnage, but in this connection it should be remembered that the cleaned ore contains from 10 to 12 per cent of combined water, which can be removed by simple roasting operations. No area having an average ratio of overburden to ore of more than 3:1 is considered workable under present conditions, and even this limit has been used in estimating the ore reserves only in those areas where there is good reason to suppose that the ore extends to considerable distances from the outcrop.

Preliminary estimates, made with the limitations set forth above, indicate that the reserves of commercial iron ore in the North Basin will prove to be between 75,000,000 and 100,000,000 long tons. The reserves in the South Basin, a large proportion of which occur in Cherokee County, are probably between 65,000,000 and 80,000,000 long tons. The total reserve of workable ore in the whole northeastern Texas field is therefore probably in the neighborhood of 200,000,000 long tons. This figure does not take into account large quantities of low-grade material that might conceivably be workable at a distant date.

FUTURE OF THE DISTRICT

Little need be added here to Baker's summary in this volume of the conditions that will affect the future of the east Texas iron ores. An immense tonnage of ore of good grade is known to exist. Mining and concentrating costs will not be excessive, although the problem of assembling ore from a large number of scattered deposits is a serious one. It should be pointed out in this connection, however, that several individual deposits contain from 1,000,000 to 12,000,000 tons of ore. Under any reasonably predictable conditions of development of the east Texas field any one of these deposits could supply all ore requirements for periods ranging from several months to several years at a time. If, on the other hand, the east Texas field should be called on to supply a large percentage of the annual ore requirements of the country, then the problem of transportation of ore to central points will be very serious.

The nearest coal of a grade suitable for blast-furnace coke occurs in Arkansas and Oklahoma. The coals west of Dallas will coke but are apparently too high in sulphur to be of much value for blast-furnace use. Should it become economically possible to utilize lignitic coal, petroleum, or natural gas in the reduction of iron ore, the east Texas ores could be utilized immediately. At the present time, however, these fuels are of importance only insofar as their abundance and cheapness will allow cheap roasting of the ores, with consequent increase in iron content and reduction in freight costs. The present projects for inland waterways along Trinity River and from Jefferson through Caddo Lake to Red River and the Gulf of Mexico deserve the consideration of all who are interested in development of the iron ores. Should these plans be realized, the shipment of east Texas ores to Birmingham or other iron centers should become economically practicable in the near future.

LEAD MINERALS AND ORES

Texas has produced 3,775,126 pounds of lead of a value of $211,381. Most of this has been derived from the Presidio silver mine at Shafter, with minor amounts from prospects in the Quitman Mountains and Altuda Mountain. These deposits are treated in the section on silver and zinc.

In 1930 the Frank Pavitte Mining Company, operating a mine on Silver Creek, 18 miles northwest of Burnet, Burnet County, in the Llano uplift of central Texas, treated 736 tons of lead sulphide (galena) ore in a 35-ton concentrating mill, producing 29 tons of lead concentrates averaging 66.45 per cent metallic lead.

The lead sulphide of the Llano uplift is disseminated in the limestones and sandstones of the Cap Mountain formation of Upper Cambrian age. In mode of occurrence there is marked resemblance to the lead deposits of southeastern Missouri, found also in Upper Cambrian strata. The mineral is known in four widely separated localities, each separated from the others by distances of from 50 to 60 miles. One is on the northeast margin of the uplift on Silver and Beaver creeks in northwestern Burnet County; a second lies between Little Bluff and Honey Creeks in central Mason County; a third is on Pedernales River in western Blanco County; and the fourth is 1 mile north of Slaughter Gap and 4 miles north of Marble Falls, Burnet County. Galena, probably of similar association, has been reported from Packsaddle, Riley, and Cedar mountains in Llano County, from Bee Rock Mountain in northeastern Gillespie County, and in a well on the Kuykendall ranch in southern San Saba County.

Most, if not all, of the prospecting was done in the vicinity of the contacts of the sedimentary rocks and the older, pre-Cambrian, granite on the mistaken theory that the granite was intrusive into the Cap Mountain formation. Therefore, it is possible that the galena may be much more widespread than has yet been determined.

Ordinarily the galena has been found around the peripheries of knobs or hills of granite upon which the limestone, sandstone, or conglomerate rests with moderate dips generally ranging from 5° to 15°. There is close association between the galena and glauconite. Small fractures, fissures, and irregular or geodic cavities contain secondary galena. Locally the galena is probably a replacement of calcite, and especially is this likely where the mineral occurs in the glauconitic and calcareous sandstone. The writer has suggested that the galena disseminated through what appears to be unaltered limestone is more probably primary (syngenetic). Much more investigation and prospecting are both justifiable and desirable.

Galena, sphalerite, and chalcopyrite occur in the limestone roof rock of an Upper Pennsylvanian coal bed in a mine near Loving, Young County. Galena enclosed in marcasite occurs in the Lower Permian 3 miles east of Quanah, Hardeman County, in Fisher County, and likewise near the L. C. Black ranch about 9 miles west of Foard City, Foard County. At the latter locality thin platy limestone is impregnated with small scattered specks of galena and disseminated pyrite, and a small bleb of charcoal in a clay bed contained galena and iron sulphide.

Galena is found in common with other sulphides of the more common metals in the cap rocks and flanking beds of the salt domes of the Gulf Coastal Plain.

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MANGANESE MINERALS AND ORES

Manganese ore is scarce in the United States, most of the needs of this country being supplied by importation from Russia, India, Brazil, Gold Coast, and Sinai Peninsula of Egypt in Africa. Of late there has been an increase in imports of ferruginous manganese ore and manganiferous iron ore. Such ore is in demand because its high metallic content and low silica and alumina content permit its mixture with high-silica, low-iron, high-manganese ores for the manufacture of ferromanganese, spiegeleisen, and manganiferous pig iron. About 95 per cent of the manganese consumed in the United States is used in the manufacture of steel, the two main basic alloys being ferromanganese and spiegeleisen. Considerable manganese is used in spring and plate steels, structural bar types, rails, and various steels used in wheels, tires, and armor plate. Such steels have excellent tensile strength and ductility, are greatly resistant to abrasion, and hence are used extensively in shoes for caterpillar tractors and truck wheels. A steel containing much more manganese —from 12 to 14 per cent—is used in castings for ball mills, pulverizers, and rock crusher jaws, it being hard and resistant to impact wear.

Manganese is an important constituent of nickel and molybdenum steels and is being used recently in a new series of alloy steels containing 18 per cent chromium and 7 to 10 per cent manganese. For every ton of steel made the requirement is 40 pounds of manganese. In the year 1929 between 45,000 and 50,000 tons of 50 per cent manganese were used in the United States chemical industry. This when free from iron is used to decolorize glass, as a depolarizer in dry batteries, and as a drier in varnishes and paints.

Other uses are in disinfectants, the manufacture of oxygen, and the making of manganese bronze and similar alloys. High-grade manganese ore containing iron is used for coloring glass, pottery, and brick and as paint pigments. Low-grade ore is used for flux in lead, copper, and silver smelting. Some manganese is used in the manufacture of chlorine and bromine, as a gas purifier, and in calico printing and dyeing. Soluble manganese salts, particularly the sulphate, are essential for the growth of certain crops, such as tomatoes in the Florida Everglades.

Manganese compounds are widely distributed in the rocks, but deposits of sufficient extent and concentration to be commercially valuable are relatively scarce, at least in the United States. No less than 111 manganese-bearing minerals are known. The oxides of manganese, dark brown to black in color, are the most common minerals. These oxides may be either hard or soft; when soft they will soil the hands when rubbed, which characteristic will often serve to distinguish them from iron oxides. The harder oxides often assume the forms of dendrites and then resemble moss or very delicate ferns. In a dry climate, such as in west Texas, rocks, boulders, and pebbles are often coated with a black, slimy, thin film of manganese or iron oxide, known as desert varnish.

Most workable manganese deposits are residual oxides formed by leaching, oxidation, and concentration at or near the surface of secondary deposits from primary manganese silicates, such as spessartite (manganese garnet), piedmontite (manganese epidote), rhodonite (a metasilicate), and tephroite. Upon solution of the primary silicates, manganese has probably been transported in most cases as a bicarbonate, sometimes possibly as a sulphate. Manganese carbonate, rhodochrosite, and rhodonite are rather common in ore deposits of hydrothermal or contact-metamorphic origin. Psilomelane, one of the oxides, occurs in hot spring deposits at the surface. Sedimentary deposits of the oxides and carbonates also occur. Lindgren[43] states that, of the oxides, manganite, pyrolusite, psilomelane, and wad are always, and braunite usually, of secondary origin, being formed under the influence of weathering, even where they descend to considerable depth below the water level.

[43]Lindgren, Waldemar, Mineral Deposits, p. 382, 3rd ed., McGraw-Hill Book Company, New York, 1928.

The supposedly largest manganese deposits of the world are beds in marine Eocene clays, marls, and sandstones, on the top of an extensive plateau in the province of Kutais, in Trans-Caucasia (Georgian Republic), Russia. Possibly even there secondary enrichment, by decomposition, has taken place. The ore beds, which are several in number, are 5 to 8 feet thick and lie at the base of the Eocene, resting on the Cretaceous, and are said to extend over an area of 10 square miles. The ore is oolitic pyrolusite, cemented with earthy manganese ore, averaging 40 to 50 per cent metallic manganese.

The high-grade manganese deposits of Minas Geraes, Brazil, appear to be in the main residual oxides derived from the weathering of schist lenses containing manganese silicates. The ores are concretions, masses, and veinlike deposits of psilomelane in the soft decomposed rock. The manganese ores of India and the Gold Coast of west Africa are of similar origin. The residual ores of Cuba and Central America are replacements in limestone and chert.

Low grades of manganiferous iron ores may be used for the manufacture of spiegeleisen, but for other purposes the ores should contain not less than 46 per cent metallic manganese and not more than 6 per cent iron, 8 per cent silica, and less than 1½ per cent phosphorous.

Three noteworthy manganese deposits are known in Texas, as follows: the Spiller mine in northeastern Mason County; the Walter Mayfield prospect, on the Jeff Davis-Hudspeth county boundary, at Chispa Summit, Trans-Pecos Texas; and deposits near Shumla and Feely in west-central Val Verde County. The manganese in Spiller Mine, Mason County, and Horse Mountain, Llano County, is in shallow surficial decomposition products of oxides derived from spessartite, tephroite, and piedmontite. It is not probable that these deposits reach very far beneath the surface or cover any extensive area.

The Walter Mayfield prospect is situated about 4½ miles south of west of Chispa section house on the Southern Pacific Railroad. The fissure vein or zone of veins is in a fault zone of large displacement which trends northwest and southeast with an upthrown block of southward-dipping Georgetown, Del Rio, and Buda limestone on the southwest, the downthrown block on the northeast having its bed rocks covered by the alluvium of Chispa Flat. The fault forms the boundary between the head of the southward flowing drainage of Van Horn Creek, tributary to the Rio Grande, and the enclosed Salt basin drainage to the northeast. The vein forms a narrow ridge visible for miles to the north and east, being, in fact, the most prominently outcropping vein in Texas. The eastern front of an eastward overthrust fault block on the west reaches within 6000 to 7000 feet of the northwest end of the vein. The fault zone in which the vein lies may pass into an overthrust to the north-northwest of the end of the vein, in which direction the amount of displacement and of the west-southwestward dip of the upthrown block increases, but beyond the southeast end of the vein the fault displacement apparently dies out into an asymmetrical anticline with 70° or more dip on the northeast flank. Nowhere along the fault zone are the bed rocks of the northeastern or downthrown block visible.

The gangue of the vein is quartz, mainly finely crystalline, chalcedonic or drusy, and yellowish-brown to rusty-stained. Apophyses or sheets of the quartz run out from the main zone and form deposits along bedding planes and cavern fillings in the limestone for distances of 1½ miles or more to the southwest of the main vein. About one-fourth of a mile southwest of the main vein in its northwestern section, travertine stalactites in a cave, collected by the writer, assayed 4 per cent lead, 2 per cent zinc, and a trace of silver. The ore minerals consist of somewhat nodular or concretionary masses of botryoidal and mammillary psilomelane and crystallized barite and hematite. A carload of psilomelane containing 43 per cent manganese, handpicked from the northeastern exposed face of the vein, has been shipped. This vein warrants further prospecting by exploring its continuation beneath the surface. There is some possibility that it may pass underground into lead, silver, or zinc deposits. Igneous rocks, both acidic and basic, outcrop in closely contiguous areas. Abundant underground water of excellent quality is obtainable close by in Chispa Flat. Transportation facilities are excellent, the old railroad grade to San Carlos being but one-half mile to the southeast of the manganese workings.

The wad and pyrolusite of the Shumla-Feely district of Val Verde County are cavern or sink deposits in "breaks" or clefts representing enlargements by solution along joint fractures and fissures, the major ones of which trend N. 40° E. These large joint fractures are approximately parallel and from 1 to 2 miles apart. The longer breaks extend for 2 miles or more and are from a few inches to 300 feet wide at different places along their course. The breaks exceptionally extend vertically for as much as 300 feet, although most of them probably do not extend so deep. Lateral breaks, running more directly north and east join the longer breaks, and the junctions seem favorable for the accumulation of the manganese. The breaks are traced easily on the surface by small pieces of manganese float, by the greenish color of the residual soil in the slight depressions between the limestone walls, and by the heavier growth of scrubby vegetation along their courses. The ore is found in the Edwards-Georgetown (Devils River) limestone, the Del Rio clay, the Buda limestone, and the Eagle Ford (Boquillas or Val Verde flags) interbedded sandy shales and limestone. Most of the better deposits are in the brittle-fracturing Buda limestone. On Section 52, Block N, I. & G. N. Railroad Survey, west of Feely, the manganese occurs in both Buda and Eagle Ford and at the contact of the two in a faulted fissure. In the Shumla-Feely area the Del Rio clay is either lacking or very thin, about 15 feet being present in a section 4 or 5 miles southwest of Shumla, consisting of 3 and 4-inch limestone layers and thin interbedded strata, all impregnated with black manganese oxides and red and brown iron oxides. The gangue of the manganese deposits consists of residual clay and boulders of limestone mixed with the ore. Thirteen average samples of ore material ranged from 2½ to 13⅓ per cent of manganese oxide.

The northeastward-trending open fissures are at right angles to the Cordilleran structure of the Pecos River syncline, the trough of which syncline is occupied by Pecos River from Sheffield, Pecos County, to the river's mouth about 8 miles south of Shumla. The Pecos River syncline was formed in probably late Tertiary time. The northeastward course of the major "breaks" or fissures is paralleled by the northeastward courses of the Rio Grande from the southernmost point of the Big Bend to the Terrell-Brewster county line, of the lower Rio Conchos in eastern Chihuahua, of the Cañon de la Alameda, which cuts at right angles across the mountain folds between the Sierra del Carmen and the Sierra Hermosa de Santa Rosa in northwestern Coahuila and by northeastward stretches of both the Rio Grande and the Pecos in the territory surrounding the manganese showings. The showings west of Shumla lie in a belt between northeastward courses of the Rio Grande and of the Pecos.

The structural axes in the Paleozoic rocks of the Marathon basin and the Solitario strike northeastwards. The Cretaceous rocks in the Shumla-Feely area lie upon the folded Paleozoic rocks. Hence, it is probable that the northeastward fissures containing the manganese deposits are a "reflection" of the structure in the underlying Paleozoic rocks, which control also the northeastward courses in the drainage lines.

John R. Roberts[44] has written as follows regarding the probable origin of the Shumla-Feely manganese:

> Wad and pyrolusite are the two manganese minerals of the small bodies of ore material of the Shumla district. These two minerals are oxides of secondary origin. Hence, it follows as a self-evident fact that the deposits are the result of leaching and secondary concentration by meteoric waters, even though they are now dehydrated. Water has had an excellent opportunity to circulate in the dip and strike joints and in the porous strata of the Comanchean formations. The belief that these are cavernous deposits is borne out by the accumulation of sand, clay, vegetable matter, and boulders, surrounding and intermixed with lenses of ore material. The lenses also contain stringers of clay, lime, and vegetable matter and seams of ore material are contained within the clays.
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> Iron in greater or less quantities is found in most rocks, and manganese is frequently associated with it. Concretions of iron and manganese are found abundantly in the upper, thin, shaly strata of the Eagle Ford formation. It is also known that other divisions of the Upper Cretaceous contain much iron oxide and probably the oxide of manganese also. Therefore, it is probable that the manganese ore materials of the Shumla district had their original source in the Upper Cretaceous formations that formerly overlay the Comanchean, but which have been eroded away.
>
> The development of caves along joints and in the porous strata of the Comanchean limestone has been in the past, and is now, a normal process in the underground erosion of that formation. To some extent this type of erosion is now active at the present surface. The numerous caves in the walls of the many canyons leading to the three rivers of the county are in fact the result of such solution. The belief is held that the manganese-bearing deposits were formed at a time when the rocks in the present surface were deeply buried beneath the younger rocks, but that meteoric waters were abundant and circulated freely in the dip and strike joints and in the porous strata of the Comanchean formations.
>
> Some of the deposits have accumulated in sinks in the Buda limestone.

An alternative to the above is that ascending solutions, of either meteoric or magmatic origin, had their upward progress checked

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[44] Roberts, J. R., and Nash, J. P., The geology of Val Verde County: Univ. Texas Bull. 1803, pp 39–40, 1918.

by the impervious cap of the Eagle Ford Boquillas flags and deposited their manganese content in solution caverns in the underlying limestone, the impervious Del Rio formation being either absent or reduced to a thin ineffective remnant. The contact between the Buda and the Boquillas exhibits throughout this territory the effects of solution of the underlying Buda limestone. Sink holes along this contact have induced several geologists to conclude there was an unconformity between the two formations, but wherever such solution occurs the overlying Boquillas flags have slumped down with basin-like structures. Evidently, in the past when most of the territory was still covered by the Boquillas much water circulated in the top of the Buda just below the Boquillas, and this water accomplished a great deal of solution. Water ascending to this contact through the vertical joint fissures may have brought in the manganese from deeper-seated sources, such as the Caballos novaculite, which in the Marathon basin contains manganese. Derivation of the manganese from descending waters could, however, take place when solution had progressed to the stage when slumping of the overlying formations was sufficient to destroy the impermeability of the overlying Boquillas flags.

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MERCURY MINERALS AND ORES

Mercury, commonly known as quicksilver, is a metal which is liquid at ordinary temperatures. It passes into a gas at a temperature of 350° Centigrade (622° Fahrenheit) and becomes solid at 40° below zero Centigrade (40° below zero Fahrenheit). When solidified, it crystallizes in regular octahedrons, with cubic cleavage. Its specific gravity is 14.4. The metal dissolves readily in nitric acid.

PRINCIPAL ORES AND MINERALS

Mercury in the metallic state is a comparatively rare mineral. Its main ore is cinnabar, which is a brilliant cochineal-red sulphide (HgS), containing when pure 86.2 per cent of mercury. It crystallizes, like quartz, in the rhombohedral division of the hexagonal system. The crystals are transparent, with adamantine luster and have perfect prismatic cleavage. Cinnabar occurs also as fine-grained aggregates of dull lustre but brillant color. The crystals vary greatly in form, from rhombohedral to thick tabular or needle-like prisms. The hardness is 2 to 2.5 (relatively soft), and the specific gravity is 8 to 8.2 (heavy). The streak is scarlet. Minerals commonly associated with cinnabar are pyrite, marcasite, stibnite, native or metallic quicksilver, metacinnabar, sulphur, calcite, iron-magnesium carbonates, silica (as quartz, chalcedony, and opal), barite, and bituminous compounds. Less common associates are realgar (sulphide of arsenic), sulphides of copper, native gold, and fluorite. Cinnabar may darken or even turn black on exposure. A little powdered cinnabar or metacinnabar mixed with sodium carbonate (common soda) and heated in the bottom of a tube closed at one end will give a mirror-like ring of metallic quicksilver around the cooler part of the tube.

Metacinnabar is the black sulphide of mercury, with the same composition and the same percentage of quicksilver as cinnabar. Metacinnabar is gray to black, with metallic luster, is brittle, and has a hardness of 3. Guadalcazarite is a variety of metacinnabar containing a little zinc and selenium. It occurs in Guadalcazar, state of San Luis Potosi, Mexico. Livingstonite is a mercury sulphantimonite ($Hg\ Sb_4\ S_6$), which occurs in groups of slender prismatic crystals of bright lead-gray color and metallic luster. Its hardness is 2 and its specific gravity 4.81. Its streak is red. It contains theoretically 24.8 per cent of mercury. Livingstonite has been found only at Guadalcazar and at Huitzuco, state of Guerrero, Mexico.

Amalgam is a variable mixture of mercury and silver, varying from $Ag_2\ Hg_3$ to $Ag_{36}\ Hg$, which crystallizes in the isometric system as dodecahedrons or modified cubes. It is silver-white with brilliant luster and from 3 to 3.5 in hardness. Lehrbachite is a selenide of lead and mercury (Pb Se with Hg Se). Some varieties of zinc blende (sphalerite) contain mercury. Tiemannite is a selenide of mercury (Hg Se). Onofrite is the sulphoselenide of mercury with the formula Hg (S.Se). Coloradoite is the telluride of mercury (Hg Te).

The mercurial tetrahedrite (variety schwartzite), a copper-mercury sulphantimonite ($4\ (Cu_2\ Hg)\ S.\ Sb_2\ S_3$), is a dark gray to iron-black mineral, with metallic or often dull luster. Its specific gravity is 5.1. Mercurial tetrahedrite occurs in a class of quicksilver deposits which do not contain cinnabar.

The secondary quicksilver minerals are especially characteristic of the Terlingua, Texas, deposits. The secondary mineral iodyrite is not known to occur at Terlingua. Calomel is the mercurous chloride of mercury ($Hg_2\ Cl_2$), known also as horn quicksilver or horn mercury. It crystallizes in the tetragonal system in pyramidal, prismatic, and tabular crystals, often complexly faceted. Its color is white, gray, yellow, or brown, with adamantine luster. The hardness is between 1 and 2 and the specific gravity is 6.48.

The other secondary minerals at Terlingua, and first described from there, are eglestonite, kleinite, mosesite, terlinguaite, and montroydite. Terlinguaite is mercury oxychloride ($Hg_2\ Cl\ O$), with small monoclinic prismatic crystals with adamantine luster, occurring also as crystalline crusts and as yellow powder. Crystals are greenish yellow, but turn olive-green on exposure. The mineral is brittle to sectile, with perfect cleavage. Eglestonite is mercurous oxychloride ($Hg\ Cl_2\ O$), forming dodecahedral and octahedral crystals of the isometric system. The color is yellow to brown. The luster is brilliant adamantine to resinous. The mineral darkens on exposure and finally turns black. It is brittle and has a hardness from 2 to 3 and a specific gravity of 8.3. Kleinite is a mercury-ammonium chloride of uncertain formula. It crystallizes in the hexagonal system in short, yellow to orange crystals that darken on exposure, but when placed in the dark, regain their original color. Its hardness is 3.5 and its specific gravity 7.9. Mosesite is another mercury-ammonium chloride. It crystallizes in small octahedra, and has imperfect cleavage, uneven fracture, hardness slightly above 3, adamantine luster, rich lemon to canary-yellow color, and very pale yellow powder and streak. Montroydite is mercuric oxide ($Hg\ O$), occurring in long, slender prisms or as equidimensional or distorted crystals of the orthorhombic system and as velvety crusts of orange-red color. It is transparent, brittle, and has a hardness between 1.5 and 2.

Most of the Terlingua ore is cinnabar, but metacinnabar, native quicksilver, and the secondary mercury minerals given above occur there also.

Hot springs at Sulphur Bank, on Clear Lake, California, and at Steamboat Springs, Nevada, and two warm sulphur springs in New

Zealand are now depositing quicksilver. The New Zealand springs are depositing also cinnabar and metacinnabar.

GEOLOGIC AND GEOGRAPHIC RELATIONS OF QUICKSILVER DEPOSITS

Dr. F. L. Ransome[45] gives the following summary statement of quicksilver occurrences:

> The ores of quicksilver, like those of most metals, show on the whole a close association with igneous rocks and with zones of fissuring. More commonly than with other metals, with the possible exception of antimony, they are associated with volcanism as opposed to plutonic igneous activity, and were deposited comparatively near the surface. It follows that quicksilver deposits as a rule are found in regions of Tertiary and Quaternary volcanic activity which have not been subjected to long and deep erosion, that they are more likely to be in the younger geologic formations than in the older rocks, and that as a class, compared, for example, with the hypogene ores of gold or copper, they do not extend to great depth. It must be noted, however, that there are some conspicuous exceptions to these generalizations. Although California deposits are in a region of late volcanic activity and many of them are closely associated with active hot springs, the ore-bodies at present most productive in that State, those at New Idria (Idria post office) and the great deposits which formerly yielded so richly at New Almaden, have no obvious connection with volcanism. The same is true of many smaller deposits in that State. The quicksilver deposits in Arizona, not yet more than nominally productive, are in pre-Cambrian schist and are by no means clearly associated with volcanic activity. The greatest quicksilver mine in the world, that at Almaden, Spain, has no known connection with volcanicity or massive igneous rocks, has been worked to a depth of 1150 feet, and the ore-bodies have been found to grow larger and richer downward. The deepest quicksilver mine in the world is the New Almaden, in California, worked to a depth of 2200 feet. The part of the mine below the 800-foot level was abandoned at a time when the price of quicksilver was low, but it is doubtful whether under any conditions that can now be foreseen it will be profitable to reopen and work the deep levels of this mine. The ground at that depth is difficult to hold and mining is interfered with by abundant water and gas.
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> Although most of the known quicksilver deposits are in regions of geologically late volcanic eruptions, it is probable that ores of quicksilver were deposited during or closely following epochs of similar igneous activity in the older geologic periods, but that many of them have removed by erosion. Some of the deposits in the older rocks, which do not appear to be related to Tertiary or later volcanic eruptions, may have had such earlier origin.
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> The quicksilver deposits of the Adriatic region in Europe, including those at Idria in Italy, Avala in Serbia, and Monte Amiata in Italy, have been shown

[45]Ransome, F. L., Quicksilver: U. S. Geol. Surv., Mineral Resources of the United States, 1917, Part I, Metals, pp. 386-387, 1921

by De Launay to belong to a single metallogenetic province characterized by Tertiary eruptions. Similarly, the somewhat scattered occurrences of quicksilver in Alaska, Washington, Idaho, Montana, Oregon, Nevada, Utah, California, Arizona, Mexico, Peru, and Chile coincide in part with the belt of Tertiary and Quaternary volcanic activity along the western sides of the continents of North America and South America. Future work may subdivide this belt into two or more provinces as regards the genesis of the quicksilver deposits, but existing knowledge is insufficient for such distinction. The deposits at Almaden, Spain, in the Donetz Basin, Russia, in Asiatic Turkey, and in China appear to be isolated occurrences that can not at present be assigned to recognizable provinces of eruptive activity and metallization.

The quicksilver deposits themselves are not confined to rocks of any particular kind or of any particular geologic age. At Almaden, in Spain, the ore-bodies have been formed by the impregnation and displacement of quartzite beds that lie between clay slates, all of Silurian age. At Oviedo, in the same country, cinnabar, with pyrite, orpiment, and realgar, occurs in brecciated sandstone and shale of Carboniferous age. At Idria, in Italy, the ore consists chiefly of Triassic shale, sandstone, and dolomite impregnated with cinnabar near a zone of overthrust faulting and was deposited in post-Eocene time. In Tuscany, in Italy, the principal ore-bodies are in Eocene limestones and shales, close to a contact between them and trachyte. In California most of the deposits are in the sedimentary rocks of the Franciscan group, probably of Jurassic or early Cretaceous age, and in the serpentine associated with the Franciscan. The New Almaden ores, contrary to previously published descriptions, are wholly in serpentine, and the New Idria ores are in sandstone and shale. In Nevada most of the deposits are in Tertiary rhyolite, although some are in Triassic or Jurassic limestone. The only important mine in Oregon is in andesite, presumably of Tertiary age. The Texas ores are in massive Lower Cretaceous limestone and in Upper Cretaceous limestone and shale (Eagle Ford). They are closely associated with small bodies of intrusive rocks of various kinds. Some of the deposits in Mexico appear to be geologically similar to those in Texas. The formerly very important deposits at Huancavelica, in Peru, are in Cretaceous or Jurassic shales, conglomerates, sandstones, and limestones, especially in sandstone, in close proximity to andesitic intrusive rocks.

It is entirely in accord with the general association of quicksilver ores with volcanic activity that the quicksilver deposits of the United States are found in the western part of the country, where the products of Tertiary and later volcanism abound, and where numerous hot and thermal springs testify to the comparative recency of much of the igneous activity.

The most abundant and productive deposits in the United States are in California. Western Texas comes next in productivity, followed by Nevada. Oregon, Arizona, Washington, Idaho, Montana, Utah, and Wyoming are all known to contain some quicksilver deposits.

A singular fact is the frequent association of bitumen, in the form of various hydrocarbons, with quicksilver. This association is well illustrated by Texas, California, Washington, Italian, and Spanish deposits. Bitumen precipitates cinnabar from solfataras. In cinnabar deposition the filling of the fissures up which the quicksilver solutions or vapors ascended usually played but a small part. The principal process is the impregnation of the country rock, of which, according to the nature of the country rock, there are two types: in the one the quicksilver fills the pores of porous rocks such as sandstone, quartzite, or conglomerate; in the other it occurs in shattered limestone filling the crevices so completely that the rock throughout is veined with ore. Most quicksilver deposits occur in much disturbed and fractured rocks and in close association with late volcanic activity. In many districts hot springs are associated with quicksilver and young volcanic rocks. This is true of the deposits of Texas, California, Nevada, Mexico, Oregon, Peru, New Zealand, Italy, and Persia.

Precipitation of cinnabar takes place either by evaporation of the solution; by oxidation; by condensation of gases upon cooling; by escape of the sulphuretted hydrogen consequent upon the decomposition of sodium sulphide; by dilution of solutions; or by the reducing action of hydrocarbons.

THE WORLD'S GREATEST QUICKSILVER DEPOSITS

The most important quicksilver occurrences will be described briefly.

Almaden, Spain.—The world's greatest quicksilver mine is at Almaden in Spain. Almaden is on the northern slope of the Sierra Morena, in the province of Ciudad Real, about 125 miles south-southwest of Madrid. The bare and unproductive mountainous country around Almaden consists of Silurian and to a lesser extent of Devonian greatly folded and faulted rocks which have been subjected to moderately strong regional metamorphism. The quicksilver deposits are associated with Silurian clay slates, interbedded limestones and white to reddish quartzites, which in places become micaceous sandstones. In the clay slates are layers of a schistose fault gouge or, perhaps, diabase tuff, known as *Piedra Frailesca,* because its gray color resembles that of the cloak of the Franciscan monks. There are several intrusions of a diabasic or melaphyric rock, and, farther away, of granite.

The quicksilver is in three porous vertical beds of Silurian quartzites, which strike east-west. These beds are known respectively as San Pedro y San Diego, San Francisco, and San Nicolas. All the mining is now concentrated in the long-worked principal mine in the town of Almaden. In this mine the three quartzite beds are impregnated with cinnabar for a length of about 650 to 800 feet. The three quartzites are separated by bituminous clay slates which contain graptolites. The thickness from the base of the lower to the top of the upper of the three quartzites is 150 feet. The principal ore-body, the San Pedro y San Diego, is from 25 to 45 feet in width, increasing in length and thickness with depth. There is no ore in the clay slates. The ore consists chiefly of cinnabar with some metallic quicksilver, a little pyrite, and traces of selenium. The gangue minerals are barite and dolomite in small amounts. The cinnabar either fills the pores of the sandstone, the total porosity of which may be as high as 26 per cent, or it forms fine veins running in all directions and having occasional druses of quartz, barite, or cinnabar. At other places, perhaps especially at greater depths, the cinnabar actually replaces the substance of the quartzite.

Schuette[46] summarizes his discussion of the Almaden deposit thus:

> It is obvious, then, that the greatest body of cinnabar ore thus far discovered upon earth was formed by conditions practically ideal for the concentration of the primary mineralization. The receptacle rock was a porous sandstone, the pore space of which was increased in depth by primary leaching. This receptacle rock was encased by walls of impervious shales. The top was practically sealed off by the same shales. Especially favorable conditions for concentration were provided by a fault gouge (the frailesca rock) cut across the receptacle rock at an angle of 45° with the horizontal, which directed and confined the mineralizing solutions to a stream along its underside.

The San Pedro y San Diego ore-body has an average quicksilver content of 14 to 15 per cent. The other two are narrower and poorer, the leanest ore being about 2½ per cent. The greatest depth yet worked is not much more than 1300 feet. Almaden is one of the most profitable of all mines and one of the most famous. It has now been producing for 2345 years. It still yields the richest quicksilver ore, that of recent years averaging 7 per cent metallic quicksilver.

[46]Schuette, C. N., Occurrence of quicksilver ore bodies: Amer. Inst. Min. Eng., Technical Pub. 335, p. 84, 1930.

Almaden and the next richest quicksilver mine, Idria in Italy, have ores which increase in value the deeper they are worked. Almaden from 1564 to 1930 produced about 209,000 tons of quicksilver. This production came from above a depth of 1180 feet. Almaden alone is able to supply the world's need in quicksilver for many years to come. The Almaden deposit above a level of 3280 feet is estimated to contain between 500,000 and 660,000 tons of quicksilver. Since 1564 the estimated production of Almaden has been $250,000,000. There has never been any other large producing mine of any substance which has made so great a net profit. It belongs to the Spanish government.

Idria, Italy.—The Idria mine is in the Julian Alps, about 28 miles slightly east of north of the seaport of Trieste, at the head of the Adriatic Sea. Before the late war, the mine was the property of the Austria-Hungarian government. It is now owned by the Italian government. The deposits are in an important overthrust fault zone, in which the older Carboniferous beds are pushed over the younger and much contorted Triassic. The direction of the overthrust is southwest, but the ore-bodies, which are very irregular in form and more or less flat-lying, trend generally northwest-southeast. Both overthrust and underthrust beds are complexly folded. The ore-bodies are post-Eocene and may be even as late as Pleistocene in age. They occur as veins, as more or less flat masses, and as stocks, chiefly as impregnations of Triassic shale, fine-grained sandstone and dolomite, and in the interstices of brecciated dolomite in the hanging wall of the great overthrust sheet. The ore consists of cinnabar in minute crystals, metacinnabar, and native mercury, with pyrite, calcite, dolomite, and smaller amounts of quartz, gypsum, and hydrocarbons (anthracite and idrialite). The deepest workings are about 1000 feet beneath the surface. The reserves are probably now about 10,000 tons. About 30 per cent of Italian quicksilver production comes from the Idria mine. Idria produced 72,000 tons from 1525 to 1908.

Monte Amiata, Italy.—The Monte Amiata district is the greatest producer in Italy. The chief mine is the Abbadia-San Salvatore, owned by the Banca Commerciale Italiana of Milan. The district is in Tuscany, in the province of Siena, about halfway between Rome and Florence. Monte Amiata is apparently a post-Pliocene volcano, from which gases and hot waters still issue. The quicksilver was worked in pre-historic times by the Etruscans.

The deposits lie along a major fracture, about 15 miles long, extending from Monte Amiata south to Montebuono. There are cross-fractures at many points along the course of the major fissures, and the most important ore-bodies are found at the junctions. The lava flows from Monte Amiata are trachyte, which covers the slope of the mountain and its surroundings. The underlying folded sedimentary rocks belong to the Jurassic, Cretaceous, and lower Eocene. Middle and upper Eocene, and perhaps Miocene, rest horizontally on the older rocks. The youngest sedimentary rocks are yellow-gray quartz sands with limy or clayey binder and veined with stringers of quartz and calcite.

More of the quicksilver ore-bodies are in the Eocene strata. The upper Eocene consists mainly of sandy to marly shales, gray to dark green-gray shales, and interstratified limestones. The middle Eocene has mainly gray to green-gray shales, reddish limestones, and light gray limestone, all interbedded in thin beds. Serpentine is found in both upper and lower Eocene, cinnabar occurring on the serpentine contacts. The lower Eocene consists of typical nummulitic limestone. Conformably under the latter is an interbedded zone of reddish marly shales. Nummulitic limestone and fine-grained limestone with streaks and nodules of dark gray chert are the next lowest rocks. Next are about 165 feet of reddish marly limestones, underlain by varicolored manganiferous clay shales, about 230 feet thick. These shales, which form the impervious cap at the Cornacchino mine, are underlain by lower Cretaceous, fractured, cavernous limestone, 65 feet thick. This varies from hard limestone to marly decomposed material containing chert inclusions and solution chambers partly filled with clay and limestone fragments. These solution cavern breccias, similar to those of the Mexican and Texan deposits, are more or less impregnated with cinnabar at the Cornacchino mine. A fractured Jurassic chert bed 130 feet thick with cinnabar in the fractures underlies the limestone. Jurassic, gray, dense limestones, in places completely decomposed to marly masses impregnated with cinnabar, underlie the cherts and are the oldest rocks in which cinnabar has been found. Antimony, in the form of stibnite, is found in the deposits.

Siele and Solforate mines, Italy.—The Siele mine, one of the oldest and formerly the most important, contained ore in large flattened "pockets," 8½ feet thick and measuring 320 to 330 feet. These pockets were solution chambers along the bedding planes partly filled with a mixture of clay, limestone fragments, marl, and cinnabar. Ores containing up to 60 per cent in quicksilver were found. The footwall is generally solid limestone covered with a layer of calcite. The hanging-wall is generally a marly limestone or a clay shale not sharply separated from the clay filling. Pyrite accompanies cinnabar. Pockets of high-grade cinnabar and clay mixtures were found in crevices in the footwall. The Solforate mine has conditions similar to those of Siele and derives its name from the numerous gas and sulphur springs in the vicinity.

Cornacchino mine, Italy.—In the Cornacchino mine, on the south slope of Monte Penna, the ore occurs in the Lower Cretaceous limestone and the underlying Jurassic cherts and limestone. Very rich ore-bodies occurred in the Lower Cretaceous limestone. They have extremely irregular forms and follow solution cavities. The richest ore was found against the impervious hanging wall, where the greatest concentration took place. The cinnabar-bearing solutions rose through fractures in the brittle chert bed and entered the limestone from below, following joint planes and fractures. Openings were enlarged by solution, leaving a residue of insoluble clay. The clay shale above formed the impervious cap rock in the axial summit of the anticline, only one flank of which has been spared by erosion. The deposits in the Jurassic limestones lie farther east along the major cross fissures. These limestones are greatly altered, and very large solution chambers were formed in which the clayey filling was impregnated with cinnabar, though generally of low grade. The deposits in the chert between the two limestones are only moderately rich.

Montebuono mine, Italy.—Montebuono is capped by Miocene or upper Eocene sandstones. The ore-bearing rock is the sandstone, 65 to 100 feet thick loosely cemented by clayey or limy material. The sandstone lies on irregular peaks of the unconformably underlying nummulite limestone. There is a large fissure, running nearly north-south, probably part of the major fault extending to Monte Amiata. Only one flank of the anticline has been preserved. The fissure, up to $6\frac{1}{2}$ feet in width, has been opened for hundreds of feet along its length and for a depth of 130 feet. It is filled with the sandstone which here contains masses of clay and is impregnated with cinnabar. Near the fissure are several funnel-shaped openings, narrowing downward. These also are filled with the clayey sand mass, impregnated with cinnabar. The upper levels average two-tenths of 1 per cent mercury, the middle three-tenths, and the lower four-tenths to five-tenths of 1 per cent. The walls of the funnels are generally covered with a layer of crystalline calcite and gashed by many small fissures, which contain bunches of ore running up to 5 or 6 per cent. The average run of the ore is about four-tenths of 1 per cent. The fissures have sharp angular walls, and the cross-rifts of the funnels were probably formed by the anticlinal flexure of the brittle limestone. The deposit might be a residual placer with cinnabar concentrated in open fissures from above, perhaps at the time the sandstone was deposited. It is equally likely, or perhaps more likely, to have formed from ascending solutions at a time later than the time when the sand and clay were washed into the fissures.

Abbadia-San Salvatore mine, Italy.—The Abbadia-San Salvatore mine is on the east slope of Monte Amiata, near the edge of the trachyte flow from the volcano. Indications of cinnabar are found for more than a mile along a strong east-west cross fracture. In the early work, cinnabar was found disseminated in totally decomposed trachyte blocks at the contact of limestone and trachyte and in the limestone. There is a clay seam, dipping some 45° into the hill, on the trachyte-limestone contact beneath which high-grade ore was found. The folded limestone was capped by a mantle of residual clay when the trachyte flow covered it.

This mine is now the largest producer, but was long considered the poorest prospect in the district. The large and rich deposits were long unsuspected. Extensive explorations based on geological studies revealed deposits of very great importance.

The nummulitic limestone and overlying Eocene sandstone were first arched into an anticline and then greatly eroded. Upon solution of the limestone, residual clays were left on the surface. This residual material was mixed with trachytic breccia from an earlier eruption of Monte Amiata. Then there was faulting near the axis of the anticline. The upthrown fault block appears to have collapsed later. thus forming the breccia which through later cementation by a silicified kaolinized groundmass formed a "trachyte-conglomerate." The area was later covered by a flow of trachyte 30 feet thick, which formed a cap rock trap for the ascending ore-bearing solutions or gases. The "trachyte-conglomerate" consists of blocks of limestone, silicified shale, sandstone, black clay shale, and trachyte. The cinnabar is distributed irregularly between the fragments in the silicified clay groundmass. Some of the decomposed trachyte blocks have been impregnated with cinnabar for distances of more than 3 feet. The overlying trachyte was quarried away and the underlying ore-bodies mined by open cuts. The average quicksilver content of the "conglomerate" down to a depth of 100 feet was 0.98 per cent, increasing in depth to over 1 per cent. A number of feeder-fissures or brecciated, funnel-shaped feeder-zones have been found, which were formed probably near intersections of cross-faults. Later developments of the Società Mercurifera Italiana on the southwest and west sides of Monte Amiata appear to have brought out no very important new features but have opened up over 300.000 tons of 0.4 per cent ore.

Very close comparison can be drawn between the Monte Amiata and the Terlingua, Texas, deposits.

Huancavelica, Peru.—Huancavelica has produced more than 1,500,000 flasks of quicksilver. A series of quicksilver occurrences extend in a northeast-southwest zone for about 37 miles, the city of Huancavelica being situated about the middle of the zone. The country rock is mainly Cretaceous limestones interbedded with shales or slates. There are outcrops of sandstone and shale and small andesite intrusions in the quicksilver-bearing zone. A large area of basalt outcrops southwest of the city and other large areas of porphyry outcrop northeast and southwest of the zone of quicksilver. Limestone conglomerates are found along the mineralized belt and to the northeast and southwest. Apparently the quicksilver deposits are along a major fracture striking northwest through the city. The fracture may mark the faulted crest of a great anticline, the nose of which has been faulted out. There also are cross fractures.

The principal ore-bodies are in the sandstone, which is capped by shale. The rocks are greatly shattered and intruded by thin sheets of andesite, which is earlier than the mineralization. The richest ore-bodies are in the sandstone where the solutions were trapped under the shale cap. In the sandstone the cinnabar is in stringers at right angles to the bedding, in grains and nodules, and in massive impregnations. The limestone contains cinnabar in fractures and joint planes, in lens-shaped masses, and as cavity fillings. The limestone conglomerate has cinnabar disseminated through the voids and in fissures which have been loosely filled with detritus of limestone and basalt. There are hot springs in the area.

The quicksilver zone occurs on the western flank of the now-eroded anticline. Other minerals besides cinnabar are pyrite, arsenopyrite, realgar, calcite, and barite. The chief mine was the Santa Barbara. The ore averaged 2 per cent or more of quicksilver and continued to a depth of 625 feet. The production of the present century has probably not been more than 4000 tons. This mine produced from 1571 to 1875 about 52,000 tons of quicksilver.

China.—The important quicksilver deposits of China are confined to Kweichow and adjacent parts of Szechuan, Hunan, and Yunnan provinces. The Kweichow plateau is an elevated block of gently folded limestones and shales, ranging in age from probably pre-Cambrian to Permian. The north-northeast-trending folding is post-Carboniferous while the great faults surrounding the elevated block (or "horst") are thought to be Tertiary. Quicksilver deposits extend over a zone 60 miles wide and 435 miles long, parallel with the fold lines. The northern deposits are in elevated anticlines. The deposits are in several roughly parallel zones, coinciding with fold-axes and the chief fault lines. Cinnabar is found in brecciated rock and in cracks and fissures, generally in limestone having shale interbeds. In the Wan Shan Chang mines, now the most important, the ore bodies lie in limestone just under the shale capping. Picked ore runs from 1.7 to 4.4 per cent quicksilver. Mining has been carried on in these mines since the fourteenth century. In some other parts of China quicksilver has been worked from at least 300 or 200 B.C.

California.—The principal deposits of quicksilver in California are in a belt in the Coast Ranges about 400 miles long and up to 75 miles wide that extends from Santa Barbara on the southeast to

Ukiah on the northwest. There have been, at one time or another since the original discovery in 1824, about 100 productive mines in this region. Production began in 1846. Most of the deposits are in rocks of the Franciscan group, probably of Jurassic age, or in the abundantly associated serpentine, the alteration product of intrusive peridotites, which is rich in magnesium and iron. Probably the greatest number of deposits are in the serpentine; others are in sandstone, generally near serpentine; and still others are in thin-bedded siliceous rocks, called radiolarian chert. The deposits of the Oceanic mine in San Luis Obispo County are in probably Miocene fine-grained sandstone, faulted against the Franciscan. The Sulphur Bank deposits on Clear Lake, Lake County, occur partly in young basalt accompanying local detrital deposits and partly in the Franciscan.

The New Almaden mine is the greatest quicksilver mine in California and the deepest in the world—2200 feet. This mine from 1850 to 1897 produced 34,000 tons. The total California production from 1850 to 1908 was 73,000 tons. Lindgren[47] describes the New Almaden mine as follows:

> The great mine of New Almaden, in Santa Clara County, south of San Francisco, is opened in shattered greenstone, serpentine, radiolarian chert, and sandstone of the Franciscan series. Considered in detail the ore-bodies are stock-works, but they are arranged along definite fissures and have on the whole a vein-like character. There are two main fissures of varying dip along and from which the ore-bodies extend. The hanging-wall is usually an impermeable, slickensided clay. There are no hot springs in the vicinity, and the only eruptive rock is a rhyolite dike parallel to the fissures.

The value of the gross production of the New Almaden mine has been estimated at $65,000,000 to $75,000,000. From 1850 to 1858 the average tenor of the ore treated varied between 19 and 37 per cent of mercury. There are more than 84 miles of underground workings, and it is said that the mine was worked to a depth of 2450 feet below the crest of Mine Hill. The workings below 800 feet are now under water. Production ceased in 1926. The Scott furnace was invented at New Almaden in 1875.

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[47]Lindgren, Waldemar. Mineral Deposits, p. 468, McGraw-Hill Book Company, New York, 1913.

Schuette[48] states, "Thus in a very general way the ore bodies of New Almaden were distributed on an irregular hump of serpentine apexing in Mine Hill. They were deposited in the voids of a brecciated zone under an umbrella of impervious attrition gouge which trapped the mineralizing solutions."

An interesting history of the New Almaden Mine is given by J. W. Furness in his paper "Mercury," U. S. Bur. Mines, Mineral Resources of the United States, 1927, Part I, Metals, pp. 60–65, 1930.

The New Idria Quicksilver Mines (Inc.), in San Benito County, has been for years the largest producer in the United States. This company owns two mines, the New Idria, worked to a depth of 1200 feet, where the ore-shoot still maintains its original length of over 800 feet and maximum width of 300 feet, and the San Carlos mine, worked to a depth of 500 feet. Ransome[49] describes the deposits as follows:

> The New Idria ore-bodies occur as rudely lenticular or pipe-like masses in steeply upturned Franciscan sandstone and shales, the shale being generally indurated and closely laminated with thin layers of sandstone. The San Carlos ore forms very irregular masses in similar but in general somewhat softer sandstone and shale of the Franciscan, and, to a less extent, in soft crushed serpentine.

Nevada.—The Steamboat Springs mercury mine is now operated for glass sand and kaolin as well as for mercury. The cinnabar here was originally deposited in granite, which has been so much decomposed that practically only the silica remains. The deposit is on a large fault marked by a line of hot springs which deposit mercury.

One of the most profitable and productive of Nevada quicksilver mines is the Castle Peak, 9 miles from Virginia City, in Storey County. The ore occurs in a soft kaolinized andesite. A deposit reported to be of large extent occurs in sandstone and opalized volcanic rock on the northeast slope of Mount Montgomery in the White Mountain Range, Esmeralda County. There are a number of hot spring deposits of mercury in the Pleistocene Lahontan lake beds.

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[48]Schuette, C. N., *op. cit.*, p. 15.
[49]Ransome, F. L., *op. cit.*, pp. 400–401.

The relatively large present production of quicksilver in Nevada is a development of recent years. That state now occupies second place in United States production.

Oregon.—The Opalite mine is in the southwestern part of Malheur County, 9 miles northeast of Disaster Peak, in southeastern Oregon. The ore deposit is about 50 feet thick by about 150 feet wide and 350 feet long. The ore averages about 0.44 of 1 per cent. Cinnabar and terlinguaite are found in a tuff altered to chalcedony.

The principal ore-body of the Black Butte mine, in Lane County, is a metallized fissure zone in andesite. The zone is about 200 feet long and up to 15 feet wide, although a width of as much as 40 feet is workable. The average tenor of the ore is 0.2 of 1 per cent.

Washington.—The Morton district is some 67 miles south of Tacoma. The mineralized area extends about 3 miles northwest-southeast and perhaps 2 miles northeast-southwest. The rocks are feldspathic, tuffaceous sandstones and sandy shales containing organic matter. There are intrusions of greatly altered andesite and basalt. The deposit dips south of west at angles of from 26° to 45°. The ore is on the contact between an altered andesite (?) and a tuffaceous sandstone-shale series. There has been lateral north-south movement along the contact, and, in the upper levels, a thrust fault has displaced the contact some 60 to 70 feet towards the west. The ore has formed under a hanging-wall of fault gouge. Locally, where favorable conditions for concentration are found under shale strata, high-grade pockets are formed. On a lower level cinnabar, pyrite, and a small seam of coal occur together. The ore has been developed for over 800 feet along the strike and thus far down to 400 feet.

Arkansas.—The Arkansas cinnabar occurrence is that farthest east in the United States. The mineral was discovered in Arkansas in 1930 and within two years had been found in a belt 22 miles long situated on or near the axis of the Cowhide Creek anticline in Pike, Sevier, and Clark counties. The country rock is the shales and sandstones of the Carboniferous Stanley and Jackfork formations, the cinnabar being deposited in fractures in sandstone beds and disseminated in sandstone interbedded with the shales. There is one quartz vein, and the ore is accompanied by dickite, a kaolin (clay) mineral considered to be of hydrothermal origin. The country rocks were intensely folded, most probably in mid-Pennsylvanian time.

Altered diamond-bearing peridotite intrusions of Upper Cretaceous age occur from 8 to 9 miles south of the axis of Cowhide Creek anticline. Probably the folded Carboniferous rocks were capped unconformably by Cretaceous sediments when the deposits were formed and the original richest part of the ore-bodies was removed by subsequent erosion. The importance of anticlinal structure, an impervious (Cretaceous) cap, and fracturing to afford open spaces are excellently illustrated in the Arkansas deposits.[50]

Mexico.—The Guadalcazar mines, about 60 miles northeast of the city of San Luis Potosi, have furnished between 50,000 and 100,000 flasks of mercury. The country rocks are folded limestones and shales of either Cretaceous or Jurassic age. There are nearby intrusions of porphyry. Metacinnabar (guadalcazarite) and cinnabar, with calcite, fluorite, gypsum, and native sulphur, occur in the limestone. The deposits near Moctezuma, 40 miles north of the city of San Luis Potosi, are reported to be fairly high grade and similar to those of Guadalcazar.

There are important deposits near Huitzuco, in the state of Guerrero, which occur as irregular pipe-like bodies at enlargements of fissures in Middle Cretaceous limestone. The ores consist of livingstonite, pyrite, and free sulphur, with much gypsum and calcite. The ore-bodies are said to be from 165 to 265 feet in diameter and up to 800 feet or more in depth. The main shaft of the Santa Cruz mine went through 144 feet of gypsum and did not enter wholly unaltered limestone until it reached a depth of 380 feet.

Quicksilver deposits are very widely distributed in Mexico, but many of the deposits have proved superficial and short-lived. Reported deposits on the Mexican side of the Rio Grande, adjacent to the Terlingua district of Texas, have not yet been developed.

Although the gypsum in the quicksilver deposits of the state of San Luis Potosi has been regarded as secondary, the present writer suggests it is primary, since he has seen extensive sedimentary deposits of gypsum lying underneath the Kimmeridge zone of the Upper Jurassic, not many miles northeast of Guadalcazar. He also has noted that the strata east and south of Guadalcazar are strongly folded and cut by both overthrust and normal faults. Guadalcazar

[50] Branner, G. C., Cinnabar in southwestern Arkansas: Arkansas Geol. Surv., Inf. Circ. 2, 51 pp., 1932.

is in a structural province which extends from Trans-Pecos Texas southwards to beyond Tampico and is characterized throughout by a type of igneous rock common to the entire region. There is, therefore, some possibility that other quicksilver deposits may be found in northeastern Mexico, particularly by testing favorable anticlinal areas in which the ore bodies do not outcrop.

Structural conditions at the Dulces Nombres mine, about 9 miles west of the Enramada railroad station, in San Luis Potosi, are much like those in the Mariscal mine, Texas. In the vicinity of Dulces Nombres, Upper Jurassic limy sandstone and Lower and Middle Cretaceous bituminous and cherty limestones are faulted and intruded by igneous rocks. Possibly Dulces Nombres Mountain is underlain by a laccolite. The uplifted mass of limestone of the mountain, dipping about 50° west, is limited on the east by a downthrown block. Z-shaped folds in the limestone of the uplifted block indicate thrusting movements. The ore is found under the gouges within the downward-opening acute angles of the anticlines. These anticlines are overturned to the east and are isoclinal. Cinnabar, native quicksilver, calcite, pyrite, and gypsum are the main minerals in the deposits. Several rare quicksilver minerals are reported in one part of the mine.

At Guadalcazar the quicksilver deposits occur along a limestone ridge for a distance of about 2 miles. The strata dip gently southwest. The ridge is a series of rounded hills, many of which are capped by gypsum. The limestone is intruded by andesite, and a parallel ridge of granite outcrops to the east. Dikes of altered granite are found in the mines. Caves are common in the limestone, and some of the limestone beds are altered (?) to gypsum. The gypsum is stated to occur in large, distinctly bedded rock masses of the same dip and strike as the interstratified limestone beds, and the present writer sees no reason why the gypsum may not be an original sediment. The small fissures connected with the ore-bodies are filled with material resembling bone ash. The minerals in the ore-body are cinnabar, metacinnabar, and two sulphoselenides, probably guadalcazarite and onofrite. Cinnabar occurs in crystalline form in fissures of the wall rock near the ore-bodies, as dull red, powdery ore scattered through the larger ore-bodies, and in stringers in the gypsum wall rock. The ore-bodies are really breccias, composed of small fragments of generally siliceous limestone, sometimes loosely cemented by calcite and gypsum but oftener by clay. In the largest producing mine, the San Antonio de Padua, gypsum, interbedded with limestone, dips 15° to 20° west. The irregular ore-bodies are arranged along a series of fault fissures nearly parallel to the stratification. The largest ore-bodies were formed under the fault breccias. The breccias are under the clayey fault gouges.

Taking into consideration the known structure of adjacent areas, the opinion is hazarded that the Guadalcazar limestone ridge was once overlain by an eastward-overthrust sheet, the gypsum hills being remnants of gypsum fault gouge serving as the "plane of lubrication" along which the thrusting took place. Minor imbricated thrust planes beneath the plane of major movement formed brecciated spaces in which the quicksilver accumulated. The gypsum and other gouge in the major overthrust plane would form an impervious trap for the ore-bearing solution. If the writer's conjecture proves correct, Guadalcazar has structural conditions somewhat similar to those of the Study Butte mine in the Terlingua district, Texas, and to those of Idria, Italy.

Mexico still has large reserves and has been an important producer. Mexico produced 4821 flasks in 1930. Two large deposits of mercury ores have been found recently in Central Asia. One is in the Turkmen Republic of Soviet Russia, near the Persian border. The other is in Southern Ferghana, at the junction of the borders of the three Soviet Central-Asiatic Republics. The latter is the richer, extending over an area of 125 miles, lying on the northern slopes of the Altai Mountains. Some deposits there have been worked by the Chinese since time immemorial. Only a single district has been so far surveyed. In this the mercury deposits, according to the most conservative estimates, are placed at 10,000 tons, rich in content, easily mined, and with good transportation facilities.

Almaden ore has averaged 8 per cent metallic quicksilver; New Almaden, California, 2 per cent; and Idria, Italy, 1 per cent. The lowest tenor of mercury ore, now profitably worked, is about one-tenth of 1 per cent.

OCCURRENCE IN TEXAS

TERLINGUA DISTRICT

The Terlingua district in Brewster County, Texas, has been an important producer of quicksilver for about thirty years. The Chisos mine alone has been credited with a production of about $12,000.000. At least four or five other mines have produced. The district and its vicinity appear to have good prospects for further development. Quicksilver was discovered here in 1894.

Perhaps the most important single feature of the Terlingua deposits is their control by anticlinal structure. This has been well brought out by Dr. J. A. Udden in his paper "The anticlinal theory as applied to some quicksilver deposits," University of Texas Bulletin 1822, 30 pp., 1918. Other important papers on Terlingua quicksilver are "The Terlingua quicksilver deposits," by H. W. Turner, Economic Geology, vol. 1, pp. 265–281, 1906; the section on "Quicksilver," by F. L. Ransome. U. S. Geol. Surv., Mineral Resources of the United States, 1917, Part I. Metals, pp. 367–455; and "Occurrence of quicksilver ore-bodies," by C. N. Schuette. Amer. Inst. Min. Eng., Technical Pub. 335, 88 pp., 1930. Much of the data herein given are abstracted from these four papers.[51]

The chief producing mines in the Terlingua district are on the southeastward-plunging end of the large Solitario anticlinal uplift. The Ellis or Mariscal mine is on the north plunging end of the Mariscal Mountain uplift. The Christmas Mountain prospects are near the summit of the high domical uplift of the Christmas Mountains. All three of these anticlinal or domical uplifts are cut by faults and igneous intrusions. The folding, faulting, and intrusion occurred in Pliocene and Pleistocene time; volcanic rocks probably covered a large part if not all the country in former times.

Intrusive igneous bodies of the Big Bend country are numbered by the hundreds. In composition they range from granitic to diabasic. The basic diabases ("basalts") are the latest intrusives. The igneous masses have the forms of sills, dikes, laccolites, stocks, plugs, and volcanic necks. There are hot springs on the Rio Grande some miles to the northeast of the quicksilver deposits.

Ore has been mined from the Edwards-Georgetown limestone, the Del Rio clay, and the Buda limestone of the Middle Cretaceous and from the Eagle Ford limy shale and the Austin and Taylor of

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[51]Other references are the following:

Blake, W. P., Cinnabar in Texas: Trans Amer Inst. Min Eng., vol. 25, pp. 68–76, 1896.

Hill, R. T., The cinnabar deposits of the Big Bend province of Texas: Eng. and Min. Jour., vol. 74, pp. 305–307, 1902

Phillips, W. B., Report of progress for 1901—Sulphur, oil and quicksilver in Trans-Pecos Texas: Univ. Texas Bull. 9 (Min. Surv. Ser. Bull. 2), 43 pp., 1902.

the Upper Cretaceous. At Study (pronounced as if spelled Stoody) Butte there is some ore in a light gray porphyry sheet. Quicksilver has been reported in the highly folded Paleozoic rocks exposed in the heart of the Solitario uplift.

The district is rugged, having steep slopes and high relief. The Rio Grande and its tributaries have done a large amount of erosion. It is likely much quicksilver has been destroyed by erosive processes. One placer deposit of cinnabar in a fissure is known.

The gangue minerals of the deposits are calcite, aragonite, clay gouge, gypsum, iron oxides, pyrite, psilomelane, and pyrolusite. A fissure filling, either of clay or of caliche-like calcium carbonate, is locally known as *jaboncillo.* Quartz and chalcedony are rare. Barite and jarosite have been found.

Quoting from Udden:[52]

The present writer, who has had opportunity to see most of the quicksilver occurrences in Brewster County, believes that structural conditions clearly affect deposition in this district and have a direct practical bearing on the finding and development of the quicksilver ores. Briefly stated, observations here indicate that the deposition of the quicksilver fumes rising from great depths has resulted from the capture of the fumes and from their retention, mainly in the form of sulphides, in structures practically resembling those which determine the retention of upwardly migrating liquid and volatile bitumens. The quicksilver deposits in almost every case occur in anticlines and domes or along decided belts in what are known as "structural terraces," or arrested monoclines. Invariably they occur in these structures at levels where the rising solutions have encountered strata that are less pervious than those immediately below. This appears to be true both on a large and on a small scale. The richest cinnabar deposits so far encountered have been found in the contact between the Georgetown (which is the upper fifty feet of a thick limestone usually referred to as the Edwards) and the Del Rio clay. The next richest horizon has been proved to be the contact between the Buda limestone and the overlying, less penetrable flags and shales of the Eagle Ford. In the Eagle Ford itself, which in this region measures at least some 600 feet in thickness, and which consists of beds rapidly alternating from compact limestone to black shale, the distribution of ore frequently shows a direct relation to these alternations. Even in the small details of these beds it has been found that pockets of cinnabar frequently underlie layers of shale. It may be that there is a coincidence of other circumstances affecting this arrangement in the distribution of the cinnabar. All of these shales are more or less bituminous and contain organic matter. This may have aided in the precipitation of the quicksilver fumes as sulphides. But that the structures themselves

[52]Udden, J. A., The anticlinal theory as applied to some quicksilver deposits: Univ. Texas Bull. 1822, pp. 8-9, 1918.

have been the most important factor is indicated by the fact that bitumens also have accumulated in the same structures. Oil has been found in the ore in the Eagle Ford in sufficient quantity to materially aid in its reduction in the furnace.

The quicksilver is distributed over a fairly wide area, extending from Mariscal Mountain on the east to the Lajitas Mesa on the west and from beyond the Mexican boundary on the south to the Christmas Mountains on the north. The known east and west extension of the district is about 30 miles, and the greatest north and south extension is at least 20 miles.

A truly adequate conception of the district is handicapped because nothing is known of the part of it which lies in Mexico. It is sure that the Paleozoic and pre-Cambrian rocks which underlie the Cretaceous were greatly folded and overthrust to the northwest in the Appalachian or Variscan mountain-making epochs of Pennsylvanian times. The visible effects of those disturbances are seen in the Marathon basin and the heart of the Solitario uplift; schists, either pre-Cambrian or metamorphosed Paleozoic, are found directly underlying the Cretaceous, on the Mexican side of the Rio Grande near the Boquillas mine. It is known also that the eastern limit of a great northeastward-overthrust province, of probably late Cenozoic orogeny, bounds the Rio Grande on the Mexican side at least as far downstream as Presidio. On the opposite or northeastern boundary, an opposite or westward to southwestward-directed possibly late Cenozoic overthrusting is visible from near the Southern Pacific Railroad southeastward to beyond Dog Canyon, where this overthrusting definitely ends by passing—in the Carmen Range—into extensive block faults. The quicksilver district itself is a series of broad and high uplifts breaking down at their margins, through a series of block faults, into dropped fault blocks.

Thus, Udden[53] pertinently remarks that:

It is also interesting to note that all the quicksilver may be said to occur within the limits of a huge sunken block just west of the main Front Range. The sinking of this block must have been accompanied by a rising of the isogeothermals [increase of heat] with reference to the parts of which this block itself consists. The deep-seated heat, which may be looked upon as being responsible for the upward migration of the quicksilver, is here, as in California, yet in evidence in hot springs. Such waters emerge just east of

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[53] *Op. cit.*, pp. 7–8.

the district on the banks of the Rio Grande. The fact that the present mines, which represent the best ore so far found, are strung on a line extending from west-northwest to east-southeast, suggests the possible existence of some linear fracture at a depth sufficient to be entirely concealed by the more superficial structures in the "outer crust" of the earth.

The present writer wishes to note something else, which may be of significance. The sunken block has witnessed extraordinary igneous activity. Possibly the rise of heated magma first caused the area to expand and to underthrust its margins. Later, upon cooling of magma, contraction taking place may have caused the differential sinking of the block along the important fault displacements. The quicksilver mineralization, especially if connected with the later or basic phase of igneous activity, perhaps indicated by the great rarity of silica and the absence of high-temperature minerals, is more or less contemporaneous with the latest fault movements.

The Solitario uplift is flanked to the northeast and southwest by synclines and down-faulted areas. Its northwestern end is buried beneath thick volcanic rocks, which rest unconformably upon different Cretaceous sedimentary rocks. At the southeastern margin of the volcanic escarpment there emerges a nearly circular dome about 9 miles in diameter, a local uplift, the summit area of which has been raised 5000 feet above the pedestal of the broader arch to the south and east. The heart of the dome has been eroded 4000 feet or more exposing a circular lower area about 5 miles in diameter in which the closely folded and overthrust Paleozoic rocks now reach the surface. The central area is surrounded by a circular hogback of Lower and Middle Cretaceous rocks dipping outwards at an average angle of perhaps 45°. This eroded dome is known as the Solitario.

There is an irregular rectangular area, reaching from the center to the southern margin of the central lower area, of felsite intrusive rock, now in places much decomposed. This rectangle is bounded on the east and west by faults. A thick sill of felsite entirely surrounds the Paleozoic outcrop. The Paleozoic strata are traversed by extraordinarily numerous dikes and sills, mostly of felsite but some of andesite or basalt. Hence, the dome is probably caused by a laccolitic intrusion.

Five miles southeast of the above described dome, and on the axial trend of the broader Solitario uplift, is Black Mesa, which is an elliptical laccolitic uplift, faulted on all four sides and with intrusive felsite exposed in the center. There has been important silicification here and quicksilver ore is associated with chalcedony; the only other locality where silica seems to be associated with the ore is in Christmas Mountain. To the southeast of Black Mesa the uplift plunges southeast at a gentle rate for 3 miles and thence more steeply. At California Mountain, north of the steep plunge, there is a neck-like intrusion of phonolite. At Clay Mountain, a mile farther north, intrusive basalt follows a northwest-southeast fault. Cigar Mountain, 2 miles northwest of Cuesta Blanca, is an intrusive. There is an abrupt and steep southward plunge of the strata along a line slightly south of east from the Presidio-Brewster county line eastwards to the east end of the Sierra del Cal. The southeastward plunge of the main anticline continues to the east end of Reed Plateau.

The southeast end of the Solitario uplift is cut by numerous faults, one system of which has the northwest strike of the main uplift, and the other system, at right angles, runs N. 63° to 75° E. But the greatest faulting occurs in the vicinity of Long Draw, on the east side of the southern end of the uplift. The Long Draw is in a sunken block, or rift, concave to the east, 9 miles long and from 1 to 2 miles wide, which extends west-northwest of the present town of Terlingua. The vertical downward displacement in the block is from 1500 to 2000 feet below the Reed Plateau, the south boundary, and from 500 to 1000 feet below the area to the north, which has two parallel west-northwest anticlines which plunge southeast in the vicinity of the Chisos mine. Towards the south, the strike of the faults swings to a more eastward direction. Nearby, in Grace Canyon, a block about 300 feet square has been dropped about 500 feet, perhaps by the collapse of a solution chamber in underlying limestone.

The southeast continuation of the broad Solitario uplift is an anticline which begins to rise about 2 miles south of Terlingua and plunges southeastwards beyond Terlingua Creek. A wedge-shaped down-dropped block extends from an apex east of Black Mesa southeast to the west foot of Reed Plateau. Reed Plateau dips gently southwest in its summit part, the dip steepening on the southwest flank. A low north-south trending anticline, with higher dip on the eastern flank, runs along Terlingua Creek near the line between Sections 248 and 229, Block G-4.

Cuesta Blanca, which is a short distance south and 3 to 4 miles east of Terlingua, has a fault on its north side, with northward downthrow of the Navarro (Rattlesnake or Aguja) against the Boquillas. This fault line is concave to the north but runs in general east-west. It is parallel with the northern of the faults bounding Long Draw rift; Cuesta Blanca is an uplifted block between the two faults.

The faults bounding Cuesta Blanca, the steep southward monocline bounding the Solitario uplift on the south, and the syncline south of this monocline all strike more east-west. The nearly east-west faults in Trans-Pecos Texas are apt to exhibit horizontal or lateral movements. The fissures which contained some of the ore bodies between Reed Plateau and Black Mesa exhibit horizontal slickensides.

The south end of the Solitario uplift, besides exhibiting the more prominent faults and folds already mentioned, is divided into a system of blocks by minor faults. One system of the minor faults trend northwest and the other system crosses it in a west-southwest direction. Some of the horizontal movements ground up the limestone along the fractures and formed fissure-breccias, while others left open spaces or narrow trenches between the fault walls. Many of the arroyos and canyons follow the fractures. The minor fractures practically die out in the Del Rio shale, which overlies the Georgetown limestone. The lodes in the Edwards-Georgetown are either in the friction-breccia or in calcite deposited in the once more-open fissures. The lodes tighten up in depth in most cases.

There would appear to be much probability that the Solitario uplift is underlain by a batholith of igneous rock, which has a steep downward slope on the south flank. In the Solitario itself and in Black Mesa, California Hill, Clay Mountain, and Cigar Mountain, offshoots from the main batholith have risen higher. Heating of the overlying and bordering sedimentary rocks by the molten magma of the batholith first caused expansion, which increased the doming, and subsequently upon cooling and consequent contraction there was some settling. The uplifting action of folding and batholithic intrusion stretched the brittle, thick Lower and Middle Cretaceous limestone, which broke by fault and joint fracturing. Both during the expansion and later contraction there would be some lateral drifting as well as unequal twisting of the fractured blocks. The intrusion of the batholith is most likely to be a consequence of the folding movement because the Solitario uplift is a structure parallel to the main mountain folds and faults. In the uparching of the thick brittle limestone, the stretching was greatest at the top and least at the bottom of the series. Hence, the fissures have their widest openings at the top and gradually close up downwards. The overlying shales at the time of the movements were under a superincumbent load of thousands of feet of rock, which pressed down upon them, tended to make them thinner, and closed up the fractures by lateral flowage in the shales. Hence, ascending solutions or gas, emanating from the underlying magma, would be trapped at the shale-limestone contacts in most cases but, exceptionally, could escape upwards through the shales, either along the edges of igneous intrusives puncturing the shales or where the amount of fault displacement was great enough to fault the shale on one side against limestone on the other and consequently afford an outlet, or where the faulting was great enough or its zone was wide enough to produce a permeable fault breccia. The faults bordering Long Draw and Well Creek dropped wedges had ample displacement to allow upward movement of water or vapor through the Del Rio and Eagle Ford shale or clay beds into higher porous formations in which the quicksilver ores could be deposited.

There is an east-west belt bordered on the south and paralleled by the abrupt southward-plunging monocline of the Solitario uplift in which the lateral movements appear best developed. This belt has the eastward prolongation of the Georgetown limestone, the outcrop of which extends to the east end of Reed Plateau. This narrow belt has probably been subject to considerable lateral shear, giving rise to horizontal movements. In fissures produced by horizontal movement, the fissure openings do not always close downwards because walls of fissures are not absolutely smooth, and plane and sidewise movements leave openings between projecting masses of the fault walls, and also such fissures may remain open to indefinite depth in shear fractures.

The thick limestones so characteristic of the Trans-Pecos and northeastern Mexico areas are likewise penetrated by extensive caverns and cavities produced by underground solution. These caverns have been formed either by the dissolving action of water reaching them from the surface or by hot corroding waters arising from underlying magma. Caverns of limestone, however formed, existing at the time of mineralization, have been partially or wholly filled by ores. Cavern filling by ores is important at Shafter and Terlingua, Texas, and at many places in northern Mexico where silver, lead, zinc, or quicksilver mines are worked.

Having now explained the openings formed in the rocks after their deposition—openings in which quicksilver can be deposited and by which it can be supplied—the sedimentary rock section will be next considered in order to learn what rocks had original porosity in which the ore could accumulate, or those which are of a nature capable of being replaced by ore.

The volcanics are the uppermost rocks, but their exposed position on the uplifted areas has led to their removal from such by erosive forces. In the Terlingua area they are now confined to the western and northern borders of the Solitario uplift. No workable ore has been found in the volcanic rocks, but it may perhaps yet be found in favorable structural situations. The volcanic rocks are favorable for ore deposition because many of them are quite porous.

The volcanic series consists of volcanic ash or tuff, tuff-breccias, lava flows, conglomerates, sandstones, and altered volcanic ash or bentonite. These rocks are penetrated by igneous intrusives. The tuffs, conglomerates, breccias, and sandstones, except where tightly cemented, are porous. The lava flows and intrusive dikes and sills are often greatly jointed by cracks caused by contraction on cooling. The volcanic series is in places greatly faulted. Impervious barriers preventing upward escape of quicksilver are afforded by some of the flows, sills, and dikes, bentonitized horizons in ash and the fine-grained sediments deposited in local ponds or lakes.

Next underneath the upper part of the volcanic series—or the part containing lava flows—is the division which is predominantly tuffaceous. The rock section from here down has been very adequately described by Dr. J. A. Udden in his paper "A sketch of the geology of the Chisos country, Brewster County, Texas," University of Texas Bulletin 9, 101 pp., 1907, from which the following account is abstracted.

The highest division is that of the Chisos beds, the thickness of which is at least 2000 feet. The Chisos beds are well stratified tuffs with some interbedded layers of clay, sandstone, and conglomerate.

The next lowest division is the Tornillo clays, composed of original volcanic ash, now largely altered to impervious clay-like bentonite and some thin lentils of sandstone. The Tornillo beds have a thickness of at least 600 feet. They are the basal strata of the predominantly volcanic succession.

The Rattlesnake, or Aguja, beds are the highest strata of undoubted Cretaceous age, being in part at least the equivalent of the Taylor of Texas and of the Pierre of the Rocky Mountains and Great Plains. The lower part of the Rattlesnake has marine fossils. Higher up, the strata become dinosaur-bearing, then coal-bearing and, at the top, carry large quantities of petrified wood. There are some beds of volcanic ash, but most of the Rattlesnake consists of sandstones, clays, and minor limestones and conglomerates. The Rattlesnake is about 600 feet thick.

Next below are the Terlingua beds, the equivalent of the Austin or Niobrara chalk. The Terlingua beds are about 1250 feet thick. They are composed of a gray marl below, which passes up into clay, which contains some thin layers of concretionary limestone and limy sandstone at the top. The Terlingua beds, like the Tornillo, make an excellent, impervious "cap rock" for trapping quicksilver solutions and vapors.

Next in downward succession come the Boquillas flags of Eagle Ford or Benton age. They are the most bituminous beds in the section and contain as well important quicksilver deposits. The Boquillas has a thickness of 600 feet. The lower part of the Boquillas consists of thin flaggy limestone with a considerable percentage of fine siliceous sand and clay which grade upwards into thin interbeds of chalk and marl. The thin strata are always greatly jointed into rectangular blocks, and the quicksilver solutions or vapors were able to penetrate rather readily the numerous joint and bedding plane spaces. The flags contain pyrite. Their great content of bitumen may have had a reducing action, influencing or causing the deposition of the quicksilver ore.

The Buda limestone averages about 50 feet in thickness. It is a compact whitish, dense, brittle limestone, generally greatly shattered by jointing. In the quicksilver district the Buda is perhaps

100 feet thick and, like the underlying Del Rio, thins to the southeast.

The Del Rio clay, from 60 to 100 feet thick, is composed of clays, sandy and clay shales, and thin-bedded limestone. The Del Rio contains large quantities of pyrite and gypsum.

The lower part of the Cretaceous consists mainly of pure and heavy-bedded to massive gray limestone, which ranges in age from Georgetown at the top to Trinity at the base. Complete sections are exposed in the circular rim rock of the Solitario and in the Carmen Range 2 miles beyond Boquillas, on the Mexican side of the Rio Grande. The upper 1500 feet of this limestone is exposed in the fault scarp of the Mesa de Anguila, at the mouth of the Grand Canyon of Santa Helena of the Rio Grande.

The upper 100 feet of the limestone succession is thin-bedded and contains numerous intercalated beds of marly limestone, which are in strata only a few inches thick. Much quicksilver ore occurs in this uppermost thin-bedded limestone and marl formation.

The part of the limestone which represents the Edwards is 600 to 750 feet thick, though dividing lines between the formations can be determined only by the fossils. The Edwards is thick-bedded limestone, which has beds carrying large numbers of chert or flint nodules.

The next lower zone is exposed in the fault scarp of the Mesa de Anguila and the fault scarps of the Long Draw down-faulted block. This is a succession, about 200 feet thick, of an impure, rather readily disintegrating limestone containing some marly layers. Below this zone there is a section, 600 feet thick, of massive limestone, with some very dark limestone and interbedded shales at the base. Below this horizon the limestone contains more detritus in increasing amount downward; the lower part of the succession often contains some interbeds of marl, shale, and conglomerate and the base is a coarse conglomerate, resting upon either closely folded Paleozoic or upon crystalline rocks. The limestone succession becomes purer and thicker to the southwest of the quicksilver district, the overlying Del Rio passing into more limy beds in the same direction.

Area west of Well Creek down-faulted wedge.—The first mining in the Terlingua district was in the area west of the Well Creek down-faulted wedge, where production was obtained from Sections 40, 41, 58, and 59, in Block G–12, Brewster County. The area is wedge-shaped, with its apex to the extreme east and widest at the northwest, in the vicinity of Black Mesa. The Edwards-Georgetown limestone on the surface has a gentle south to southeast dip over the top of the area but is down-dropped along a fault at the northeast margin and dips steeply southwards in a narrow monoclinal zone at the south edge. Erosion has comparatively recently stripped the Del Rio clay, Buda limestone, and Boquillas flags from most of the top of the area, but a remnant of Del Rio, capped by Buda, still remains in California Hill. The Buda limestone caps the series of hills to the south, which extend from Tres Cuevas Mounta'n to the northeastern end of the Sierra del Cal. This line of hills, concave to the north, is the northward-facing scarp of the steep southward-dipping beds of the south-bounding monocline. The southward dip in the monocline ranges from 20° to 60° and is broken to the north of the scarp by a fault with upthrow up to 50 feet on the south side. The belt of the steeper dips south of the fault is about one-half mile wide, and thence south for 3 miles the dip is gentler. In ground plan the monocline is arcuate.

Udden[54] describes the deposits as follows:

The ore in the Marfa and Mariposa mine, and also in the old Terlingua mine, has been deposited mostly in joints, fissures, and cavernous openings that extend down in the upper surface of the Georgetown limestone. The material filling these fissures is locally known as *jaboncillo*. It is a material of mixed nature, consisting in places largely of clay and in other places of material quite like caliche. It is evident that it has been formed in these fissures partly by precipitation from solutions which have followed the lower surface on the Del Rio clay, and partly also by the Del Rio clay itself which has settled perhaps gradually into solution caverns, *pari passu* with enlargement by solution. The jaboncillo frequently contains fragments of the limestone itself and is in places not unlike a fault breccia, cemented with calcareous material. At the surface, this jaboncillo in places changes into caliche, clearly formed at a recent date. Even this caliche contains fragments of cinnabar, which apparently have been entombed quite recently in the formation of superficial caliche. The fissures extend to varying depths and no doubt in some place, or places, join "pipes," most probably along fault lines, through which the quicksilver has ascended. The great number of these ore-bodies gives out in less than twenty feet below the upper surface of the Georgetown limestone and the mining on most of the hills in the sections mentioned has been done in shallow pits which stud the land at the present time. In places,

[54]*Op. cit.*, pp. 14–15.

ore occurs at greater depths and some fissures have been found with open vugs set with calcite and gypsum crystals.

It would seem altogether likely that further prospecting may result in the finding of deeper pipes and it would seem quite probable that these should, as already stated, be found in some of the faulted fissures known to exist.

Udden[55] thus explains the occurrence of the ore:

In the Marfa and Mariposa mine and in the old Terlingua mine much of the ore has come from brecciated fissures in the upper surface of the Edwards-Georgetown limestone. This was originally directly covered by the next to impervious Del Rio clay, which at the present time is mostly removed. Evidently in this case, also, the ore was precipitated from rising solutions at a level where these were hemmed in by the impervious cover of the clay. As cinnabar has been found in this mine also in a porphyry, the ore is in that respect in a situation quite similar to that at Big Bend (Study Butte). If the mineralized solution followed the course of a body of an intrusive in the limestone it would be likely to have a comparatively open and unimpeded passage along this intrusive, as long as this traversed the limestone, for in limestones dikes are quite uniform in their development. But reaching the overlying clay the solution (or vapor) would find the dike less regular and the clay also would hinder its ascension. The solution would naturally follow the upper surface of the limestone and precipitates would find lodgement in its fissures under the clay.

The limestone contains many solution caverns, as well as open fault and joint fissures. Dr. W. B. Phillips[56] states:

At more than one locality in the Terlingua district considerable masses of cinnabar have been found in piles on the floors of caverns which have no visible outlet to the surface. One such cavern was encountered at a depth of 45 feet from the surface and was 25 feet high, 60 feet long and 40 feet wide. On the floor of this cavern there were piles of cinnabar carrying more than 30 per cent of quicksilver, some of the pieces exceeding 50 pounds in weight. Stringers of rich ore made out in many directions from the caverns and the stalactites were in numerous places coated with cinnabar. Within a mile of this place a similar cavern was found also with piles of rich cinnabar on the floor.

The secondary quicksilver minerals, already noted, occurred in the surficial deposits of this area, in which, also, the pyrite is mostly altered to the iron oxides, hematite and limonite.

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[55]Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Texas. Univ. Texas Bull. 93 (Sci. Ser., Bull. 11), pp. 89–90, 1907.

[56]Phillips, W. B., The quicksilver deposits of Brewster County, Texas: Econ. Geol., vol. 1, p. 158, 1905.

Schuette[57] says that:

> A large part of the production of this [Marfa and Mariposa] mine came from what might be called the detrital deposits left on, and in irregularities of the surface of the Edwards-Georgetown limestone, where the Del Rio clay, the original cap rock, had already been removed by erosion. Later underground mining developed ore-bodies under and against the Del Rio clay and as far down the feeder fissures as the ore persisted.

Evidently a very large amount of cinnabar has been removed by erosion. This should form placer deposits along the drainage courses draining the area but the placer has not been worked, perhaps because there is no water for its concentration.

One of the main lodes (No. 11) was along a dike, one of the two dikes of California Hill, which in places spread out between the strata as intrusive sheets. The deposits may be called friction-breccia and calcite lodes along more pronounced fissures, more pockety cavern-fillings and bedding-plane deposits. Cinnabar formed wherever there were openings in the rocks accessible to the source solutions or gases.

Uplifted block between Well Creek and Long Draw down-dropped blocks.—The productive area in this block was mainly on Section 38, Block G-12, which lies to the east of Clay Mountain. The fissure veins strike west-southwest. The Colquitt-Tigner Company worked the Excelsior or the northern of the veins. This vein was a distinct, well-filled fissure varying from 8 inches to 3 feet in width, opened by mining for a distance of several hundred feet. The vein was cut by a laterally-displaced fault and displaced about 30 feet near the west end of the workings. The country rock is the thinnest-bedded part of the Georgetown limestone, the beds being from 1½ to 3 feet thick with interbedded layers of marly material. The fissure widens above, where it cuts the thinner-bedded rock. The fissure filling was mostly banded calcite, with amorphous and crystalline cinnabar and iron oxides. Masses of almost pure cinnabar weighing several hundred pounds occurred. The ore-bearing streaks varied much in width. There is little or no vertical displacement in the rocks forming the walls of the fissure.

The Tierra lode is over 2500 feet long, with a fissure open to the surface which varied from a fraction of an inch to several feet in

[57]Schuette, C. N., *op. cit.*, p. 35.

width. The fissure was to a greater or less extent filled with loose material washed in from above, comprised in part of red shaly materials and in part of calcite. Surface water, percolating downward, dissolved some of the calcite of the lode and the adjoining limestone, forming open fissures or caves. On the 100 and 150-foot levels fossil bones, of mammals probably of Pliocene age, were found. A body of good cinnabar ore in a soft matrix gradually disintegrated and enriched the detritus accumulating in the open fissure.

At the east end of the Tierra lode an underground water channel with a surface sink hole developed to the depth of more than 410 feet. The Little 38 mine (W. F. Oakes, Jr.) worked the material accumulated in this sink hole by means of a shaft 1024 feet north and 1846 feet west of the southeast corner of Section 38. The deposit was described by J. T. Lonsdale in his paper "An underground placer cinnabar deposit." Economic Geology, vol. 24, pp. 626–631. 1929, and by C. N. Schuette in his paper "Quicksilver," U. S. Bur. Mines, Bull. 335. p. 30, 1931. The channel is irregularly pipe-shaped, varying from 3 to 25 feet in longest cross section, irregularly contracting and expanding in size, and going down in an irregularly vertical direction. The chimney-like solution channel was filled from the surface downward by a red finely-laminated clay or silt, containing fragments and cobbles of limestone and grains and occasional cobbles of cinnabar. Bones of Pleistocene animals were found in the filling.

Reed Plateau is a small tableland of uplifted Edwards limestone, less than 1 mile wide and 4 miles long, lying to the southeast of Section 38. The south side of the plateau is an abrupt southward-plunging monocline. The Edwards limestone here occupies an area of higher structure than the blocks across Well Creek and Long Draw dropped blocks, the line of the southward-plunging monocline being 1½ miles farther southeast than in the Sierra del Cal. The Coltrin's Camp quicksilver prospect is situated under the south escarpment of Reed Plateau, where there are veins of cinnabar at right angle to the longer axis of the plateau. These veins are in the Eagle Ford (Boquillas) formation.

Chisos and Rainbow mines east of Long Draw.—These mines are the most productive in the district. Two parallel anticlines, running from west-northwest to east-southeast, here plunge to the southeast.

They adjoin on the northeast the Long Draw sunken block. The Chisos mine is situated where the plunge is steepest, causing cross-fracturing of the south anticline, the south side of which coincides more or less with the compound, lagging, fault fissures separating the Long Draw valley block from the upthrown block to the north. The plunge on the structure here takes the Eagle Ford beneath the surface. The lagging blocks in the fault zone nearly always dip in the direction of the drag. One of the lagging blocks occurs where most of the quicksilver has been mined. This block is cut off to the west by an oblique fault, extending north-northwest, and crossing the north fault of the Long Draw rift. Most of the fault movement has taken place between the south side of this lagging block and the sunken rift block, the displacement here amounting to about 1000 feet, while the displacement between the lagging block and the main upthrown block on the north is less than 40 feet. Ore is found in all three of the faults and in cross-faulted fissures as well. The ore improved on the contact between the Buda limestone and Eagle Ford, and fine ore is found at the contact of the Georgetown limestone and overlying Del Rio clay, north of the fissure separating the lagging block from the main block on the south side of the southern anticline. This is the main productive fissure, with ore in irregular bodies. Calcite is the principal gangue, the accompanying pyrite carrying a small amount of gold. Much low-grade ore occurs in the bituminous marls and flags close to the fissures. The productive ground is more scattered on the upper than on the lower levels. On the lower levels there is a pipe-like ore-body, where the sharpest plunge of the ore-body is crossed by a zone of what may be called a fault-breccia, consisting mostly of large blocks and smaller fragments of Buda limestone scattered through a matrix of broken and fractured Del Rio clay. The ore-bodies scattered out upon reaching the thin-bedded Eagle Ford flags above. Udden[78] remarks:

> From this circumstance it would be natural to expect that some solutions traversed the ground to the north under the Del Rio clay, away from the same fissures and their principal zone of deposition can be expected here, as at other places, at the Del Rio-Georgetown contact, owing to the impervious nature of the Del Rio clay . . . . A recognition of the significance of these facts enabled the writer many years ago to predict the depth and place at

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[78]Udden, J. A., The anticlinal theory as applied to some quicksilver deposits. Univ. Texas Bull 1822, pp. 28 30, 1918

which the richest ores in the Chisos mine would be likely to be found. This prediction has in so far proved satisfactory that it encouraged the management to go through several hundred feet of somewhat unprofitable ground, and that this work enabled it to reap a satisfactory reward after some years of more or less unprofitable exploration of the upper levels in the mine.

Below the 600-foot level most of the ore—and the richest found—forms a single remarkable chimney, 75 to 100 feet in diameter, extending from a little above the 600-foot level down to the 750-foot level or lower. Ransome says this pipe or chimney may have been formed by the collapse of a solution chamber in the massive Edwards limestone. "The ore in this dropped mass is a chaotic breccia consisting chiefly of fragments of Buda limestone with cinnabar, native quicksilver, free sulphur, and marcasite or pyrite, and perhaps other minerals less readily recognizable, as an interstitial filling and as a replacement of some of the smaller limestone fragments." Unfortunately, however, there is water on the lower levels of the Georgetown-Del Rio contact. The Rainbow mine, just to the west of the Chisos, is operating farther up the dip, where the workings are dry. The Chisos workings now extend about 3000 feet laterally and 900 feet vertically.

Prospect on Section 248, Block G-4.—Prospecting has been done on the west, more gently-dipping limb of a low north-south anticline, the ore being along fissures running at right angles to the fold. The mercurial solutions in passing upwards have been deflected on the upper contact of the, at present exposed, more open layer of the Austin chalk, with the less pervious and more clayey Taylor marl that overlay it at the time the ore was deposited. There is here a vertical pipe of oval or circular shape, perhaps 75 feet in diameter, which is composed of angular fragments of shale and sandstone, cemented by calcite and a bituminous substance. The bitumen ran down the sides of the drifts from cavities in the cemented material. Possibly this pipe may have been caused by an explosion of volcanic gas or it may be the filling of a sink hole. Cigar Mountain, about 1 mile to the northwest, is composed of igneous rock.

Stringers of cinnabar occur in the rhyolite of Maverick Mountain, Croton Spring, and other places.

Study Butte.—Study Butte is on Section 216, Block G-4, just west of Maverick Mountain and about 1½ miles east of the prospects on Section 248. The Big Bend and the Dallas mines on Study Butte are now jointly operated by Brewster Quicksilver Consolidated. A large sheet of andesite or trachyte about 400 feet thick is intruded along the plane of a probable thrust fault, the fault plane dipping about 45° to the north. The intrusive sheet flattens and becomes nearly horizontal at the base of the north slope of the butte. The Austin of the hanging-wall overlies the Taylor of the foot-wall. Shrinkage cracks and brecciated areas in the intrusive sheet are filled with ore as are also open spaces in the underlying and overlying rocks. The overlying Austin chalk has close-textured shales which formed an effective barrier for the mineralizing solutions or vapors. The ore-filled fissures in the andesite have steep dips to the northwest and a northwest-southeast strike. Some cross fissures run northeast and southwest. The ore is in irregular stringers.

Mariscal Mountain Mine.—Mariscal Mountain, in the southernmost part of the Big Bend, is the place farthest southeast in which quicksilver has been found in Texas. Mariscal Mountain is a long north-south-trending anticlinal fold, which is highest structurally in Mexico. The Rio Grande crosses this anticlinal mountain in a canyon which has a maximum depth of 1500 feet. The western periphery of the anticline has a vertical flank dip, and the eastern periphery is a fault with a downthrown block about 1½ miles wide on the east side of the fault. The Edwards and Georgetown limestone forms the highest part of the mountain. These formations plunge under the surface on the northwest nose of the plunging anticline, and it is here that quicksilver has been produced, the property being originally known as Lindsey's mine. The mountain part of the anticline in Texas is about 12 miles long, with axis west of north. This anticlinal mountain is about 5 miles wide at the Rio Grande, tapering at the north to a fairly sharp point.

The Eagle Ford or Boquillas flags, which dip under the Austin and Taylor on the north "nose" have a thickness of about 600 feet and contain two sills of acidic intrusive rock, which are folded with the sediments. The northward-dipping "nose" plunged abruptly and is there broken by cross fissures. It is here where abrupt increase in the rate of dip takes place with cross-fracturing that the ore is found. The ore-bodies are in the middle part of the Eagle Ford, which consists of limy shaly flags, which are quite compact and frequently highly bituminous. They contain some small pockets of oil and there has been noted some small "seepage" of solid bituminous material. Some ore occurs at the contacts of the flags with the intrusive sills, and the igneous rock is slightly impregnated with cinnabar. Very likely richer deposits are to be expected at the contact of the Buda limestone and Eagle Ford and at the contact of the Georgetown with the Del Rio. However, water entering the limestone in the Rio Grande canyon may be troublesome in workings of the Georgetown-Del Rio contact in the lower levels, down the dip.

The axis of the anticline is cut by an oblique fault striking N. 20° E., while the plunging anticline near the mine strikes N. 25° W. The minerals may have risen along this fault or else along the intrusive sills. Overlying impervious shales formed an impermeable barrier, under which the lodes were formed.

Placer cinnabar has been picked up on the sides of Mariscal Mountain and traces of cinnabar found in prospect holes both north and south of the mine. On the east side of Mariscal Mountain, 3 miles west and 1 mile south of Solis's ranch, cinnabar occurs in and near a dike cutting the lower Boquillas flags.

Christmas Mountain prospects.—Christmas Mountain is the northeasternmost place at which quicksilver has yet been found. The location is about 12 miles northwest of the Chisos Mountains and about 13 miles northeast of the present town of Terlingua. Christmas Mountain, one of the most perfect domes in the region, has a length from northwest to southeast of about 5 miles and a width of about 4 miles. The center of the dome has been uplifted at least 4000 feet above the surrounding base. The surface Edwards limestone of the dome has likely been uplifted by an underlying intrusive laccolite. There are dikes east and south of the dome, which radiate from its center. The Upper Cretaceous strata at the foot of the mountain dip outwards at high angles. Almost certainly the top of the dome was formerly covered by the Upper Cretaceous. The east and northeast sides of the dome have gentler dips than the west and southwest sides. The west side of the mountain is at some places much sheared and faulted. A zone of faulting extends from there southwards, with some southeast offsets, to the east side of Burro Mesa, Burro Mesa being dropped in along the west side of the fault and downthrown to a greater extent than any other block in the whole Big Bend country. At the south side of Christmas Mountain there are calcite-filled fissures in the limestone.

There is a small cinnabar prospect on the highest point of Christmas Mountain. The mineral occurs in what appears to be cavernous places in the Edwards limestone, evidently part of the mineralization which once existed under the impervious capping of the Del Rio clay. Other small prospects are reported from fissures on the west side of the mountain. At several places at the foot of the mountain, near the Del Rio and Buda contacts, cinnabar has been found in fissures and cavernous rocks. Float has been reported from the east slope of the mountain. There is a northwest-southeast fault in the Edwards limestone in the vicinity of the cinnabar prospect at the summit of the mountain.

Perhaps a formerly large cinnabar deposit has wasted away by erosion in the higher part of the Christmas Mountain. Although the top of the mountain is 2000 feet above the base, and waterless, and consequently a difficult place to exploit, there is a possibility that quicksilver may be found in the lower horizons of the Cretaceous underneath. Geophysical work might determine the depth and form of the upper surface of the probably underlying laccolite, and diamond drilling might discover ore-bodies. Such ore-bodies would likely be above the level of ground water. If sufficiently porous or fractured strata, sealed in above by impervious rocks, occur here in either the Trinity or the Edwards, conditions are favorable for the presence of quicksilver.

REPORTED DEPOSITS IN THE CHISOS MOUNTAINS

Cinnabar float has been reported from near Laguna, on the top of the Chisos Mountains. The center of this large mountain mass is occupied by a very complex intrusion, either an enormous plug, an unusually high laccolite, a bysmalith, or a large volcanic neck. On the west side this igneous body cut through nearly vertically horizontal strata thrown into small but abrupt folds. On the south, also, the sediments end abruptly against the igneous mass. On the north and east sides, however, the sediments have been stretched out into a half arch which bends over the top of the intrusion. Here the Eagle Ford has been uplifted to 7000 feet above its position around the base of the mountains, and the cinnabar float has been reported from the vicinity of the highly uplifted Eagle Ford strata.

CONDITIONS DETERMINING THE OCCURRENCE OF THE QUICKSILVER

The facts given above should make it sufficiently obvious that there are few places in the world where the factors determining the deposition of original, or primary, metallic ores, introduced after the formation of the country rock, can be determined as surely as in the Terlingua quicksilver district of Texas. Students of ore deposits are often justifiably confused by the minor complexities shown by the different forms assumed by the lodes under such conditions as those at Terlingua. But at Terlingua these minor complexities, which, to be sure, the actual miner should thoroughly understand, should be disregarded in favor of the main, outstanding, and readily grasped facts. These are:

(1) The structural control of ore deposition, the quicksilver being concentrated in anticlines and anticlinal-like structures in all essential respects just like oil and gas are concentrated in productive oil and gas fields.

(2) Attempts to make a minute classification of the different forms of ore-bodies no doubt have their value, but any opening in the rocks where quicksilver can enter and accumulate is apt to contain ore.

(3) Relatively impervious clays, shales, marls, or intrusive dikes, sills, sheets, or, in fact, any kind of tight rock keep the quicksilver solutions or gas confined within anticlinal or anticlinal-like structures and direct the quicksilver-carriers in an ascending direction. If such hollow dome-like sheets are not sufficiently fractured to afford channels through them, the quicksilver must accumulate beneath their lower surfaces. If channels through them are afforded, some of the quicksilver will rise to higher rocks or in some cases to the surface. Such channels are not always filled with ore but may be so filled when there is not adequate space for all the quicksilver supplied to deposit above them.

The quicksilver has precipitated out and formed deposits either because of cooling, release of pressure, mingling with solutions or gases of different composition or by processes of chemical reduction owing to reactions with substances in the wall-rocks.

Bituminous matter may or may not have played a necessary part in ore deposition. The Cretaceous shales, marls, flags, and clays are all bituminous, the strata of the Eagle Ford being especially so. The limestones contain also a little bitumen. The bitumen and oil found in some workings may, however, have been distilled from the sediments by the heat of the igneous intrusions, by the heat and pressure generated by folding and faulting, or by the downward pressure exerted by the superincumbent load of sediments, now removed by erosion. Hence, the presence of bitumen may be mainly or largely fortuitous.

The Lower and Middle Cretaceous limestone throughout its 2000 feet or so of thickness appears to have been in many places pervious to the passage of heated solutions or gases. Gases will penetrate smaller openings than liquids. Fracturing of the limestone may have afforded the channels. It is possible that heated solutions or gases may have dissolved the channels through more soluble parts of the rocks. The quicksilver is likely to have emanated from the hot igneous magma and may have followed the margins of the hot rock until it reached openings in the intruded rock through which it could escape. It has been shown already that openings in the rocks in this district were formed by perhaps all the processes known to have fractured or dissolved rocks. At any rate the quicksilver-carrier was enabled to reach open spaces of sufficient size in which to deposit its load of mineral and was in places trapped, or its further progress at least greatly inhibited, by relatively impermeable rock barriers. If the quicksilver was carried mainly in the form of gas its deposition may have been caused merely by condensation upon cooling as temperature was lowered. Thus the earliest-deposited quicksilver may have reached the highest levels at the time underlying rocks were sufficiently hot to prevent its condensation. Then, later on, as the lower rocks gradually cooled, the zone of deposition was lowered into them.

The cinnabar, from which by far most of the mercury is derived, is primary. The only secondary quicksilver minerals occurring in any amount at least are in the western part of the area, centering around California Hill. The secondary minerals occur only close to the surface, where the oxygen of the air has penetrated. They have been formed under the conditions of desert-weathering and, very probably, above the ground water level. There is apparently no zone of secondary sulphide enrichment of any important amount, because the water level lies deep in the desert area; there has been relatively little alteration in the dry climate except solution of limestone; and the primary ore, cinnabar, is resistant to the more common chemical activities. However, the native mercury may have been reduced from compounds through the agency of the bitumen. This is not certain, for it may have sublimated directly from vapor, upon cooling, or, perhaps, release of pressure, either before, after, or during the deposition of the cinnabar.

Perhaps closer analogies to the Terlingua district can be found in the Panuco, Mexico, oil field than in other oil fields yet known. The rocks in both places are of the same age and possess similar lithology. In both cases the production is confined to anticlinal "noses" of larger structures. Intrusive igneous rocks occur in both. In both, the greatest production has come from fissures in limestone.[59] Both are in the same structural, petrographic, and Cretaceous rock province. The ore deposits of eastern Mexico, which occur in the intermediate area between, are likewise controlled by similar anticlinal structure.[60]

FUTURE POSSIBILITIES

Everyone who has published an account of the Terlingua deposits has expressed an opinion that other profitable quicksilver deposits may be found there. This opinion is based on the anticlinal structural control of the ore-bodies, the widely distributed intrusive rocks, the folding and faulting prevalent over a wide extent of the territory, and the presence nearly everywhere of the Cretaceous sediments in which most of the deposits occur. It is, however, equally apparent to all that there is little likelihood of any more quicksilver mines being discovered on the Texas side of the Rio Grande by merely surface prospecting.

It is absolutely necessary that further exploration and exploitation be guided by competent geologic advice. The application of geology

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[59]Baker, C. L., The Panuco oil field, Mexico: Bull. Amer. Assoc. Petr. Geol., vol. 12, pp. 395–441, 1928.

[60]Baker, C. L., General geology of Catorce mining district: Trans. Amer. Inst. Min. Eng., vol. 66, pp. 42–48, 1922.

is perhaps necessary even more in quicksilver prospecting and mining than in the deposits of other metals and ores; certainly in the Terlingua area geologic guidance is more essential and apt to yield more profit even than in other quicksilver districts. The reasons are that the rock formations are exceptionally regular and an adequate conception of the structure all important. The rocks are exceptionally well exposed, and, although the structure is complicated, it can be worked out correctly and applied to the discovery of ore-bodies if sufficient time is spent upon it by sufficiently able and energetic structural geologists.

A single instance ought to be sufficient to prove the point. Had the surface country rock at the Chisos mine been the impervious Terlingua marl instead of the relatively brittle, much jointed and hence relatively pervious Eagle Ford flags, there would have existed no signs of cinnabar on the surface and a mine which has already had a life of thirty years and a production of perhaps $12,000,000 would most probably not yet have been discovered. Or, if the fault displacements had been much less, *i.e.*, not sufficient to displace entirely the full thickness of the Del Rio clay, no quicksilver would have entered the Eagle Ford beds outcropping on the surface. This is not the whole of it. The Chisos mine would have been abandoned long since had not Dr. J. A. Udden, by his geologic acumen, discovered new ore bodies fairly constantly, and the richest ore in the mine would never have been reached if Dr. Udden had not been able to persuade the management to spend considerable money in penetrating barren ground in order to reach it. Much the same history has been experienced in the Shafter silver mine, the only other important metal mine in Texas. There geologic study proved that the faulting occurred later than the ore deposition; hence orebodies, supposedly exhausted, were found to occur beyond the fault displacements. If the United States maintains a production of the essential metal, quicksilver, commensurate with her needs, it is most likely it will be in further development in either California or Texas or both, and in both competent geologic guidance is the first essential. Almaden, in Spain, can probably supply quicksilver for the world at the present rate of consumption for a long time to come, but that supply may be cut off in time of war. Also, as the sequel will show, new uses of quicksilver are apt to develop at a greater rate than the production of Almaden alone, or even Almaden plus Italy, can satisfy adequately. Hence, the United States needs to develop more reserves in quicksilver than she now has. The last war drew very heavily on her reserves, even on low-grade reserves which can only be worked adequately with war time extremely high prices for quicksilver.

Quicksilver exploration in the Big Bend area of Texas is, however, a costly undertaking. It should not be undertaken until much, if not all, the area mapped on the Terlingua and Chisos Mountain topographic quadrangle sheets of the United States Geological Survey has been worked, slowly and painstakingly, by very experienced structural geologists. Then it is necessary, next, to test extensively by diamond drilling the areas where the structure is most favorable for profitable quicksilver. The quicksilver lodes are scattered and irregular and most apt to occur in more or less vertical fissures. Even in the most promising territory a number of drill holes may miss ore altogether and yet that territory may have large and profitable lodes. In the similarly fissured and fractured territory of the producing part of the Panuco oil field, only one-fifteenth of the holes drilled in the last years yielded a profitable amount of oil. Even when the drill cores show good ore-bodies, shafts must be sunk to them and lateral drifts or tunnels run from the shafts. It may be advisable to expend considerable sums in geophysical work. Quicksilver ore occurring in the structures of lower elevation may be beneath the ground water level.

Land and mineral right owners—and among them the state of Texas—must be made to realize that no deposits of metallic minerals can pay anything like the amount of royalty now procured for oil and gas. Expenses of underground mining are greater, and the percentages of profit are generally very much less than those of developing and producing oil and gas. If too high a royalty is exacted, no one can afford to explore for quicksilver, or, if he should explore and find it, he could not afford to mine it.

In some cases, further exploration is advisable of deposits already mined or in the vicinity of those deposits. Some of these places have already been mentioned. Others exist perhaps under the rocks covering the Georgetown-Edwards limestone within a relatively short distance south of already explored ground west of the present town of Terlingua.

It is obviously unfortunate that erosion has already removed so much of the impervious cap rocks from the largest, highest, and most favorable structures in which the most favorable ore-bearing formation known, the Georgetown limestone, is likewise wasted away. There are left, however, a number of lower anticlines or domes or sealed fault blocks, still capped by impervious rocks.

USES OF QUICKSILVER

According to Ransome[61] the following are the principal uses of quicksilver under normal conditions, stated in general order of decreasing importance.

Quicksilver enters largely into the manufacture of drugs and chemicals, including calomel and corrosive sublimate. Mercuric oxides and mercury salts are also used extensively in the manufacture of certain chemicals, such as glacial acetic acid, phthalic acid, and phthalic anhydrite, into which mercury does not itself enter. Mercury fulminate, with the chemical formula $Hg(CNO)_2$, is used as a detonator for high explosives, and to a less extent than formerly in small-arms ammunition. It is made by treating mercury with strong nitric acid and alcohol.

As mercuric sulphide, mercury forms the brilliant red pigment vermilion. The metal is employed extensively in electrical apparatus, including rectifiers for changing alternating into direct current, mercury-vapor lamps, and storage batteries. In the manufacture of felt hats from rabbit's fur, mercuric nitrate is used to roughen the hairs so that they will adhere together, a process technically known as "carroting." Metallic quicksilver is employed in the amalgamation of gold and silver ores, although of late years the wide application of the cyanide process has decreased this use. In the metallic state, also the metal is utilized in the manufacture of instruments, thermostats, gas governors, and other appliances. Mercury enters into the composition of some antifouling marine paints for ship bottoms, a modern and at present a rapidly increasing use. The mercury for this purpose is generally employed as the red mercuric oxide, its efficacy depending upon the gradual conversion of the oxide to the poisonous bichloride by the sodium chloride of salt water. About 12 ounces of mercuric oxide or 11 ounces of metallic mercury is contained in each gallon of paint, which covers 243 square feet. Mercury is also used in certain compounds for preventing boiler scale, in cosmetics, and in dental amalgam. Silver nitrate has to a large extent been substituted for mercury in silvering mirrors. A small quantity of quicksilver, not more than 2 or 3 flasks annually, is used in floating certain types of revolving lights in lighthouses. The quicksilver so used, like that in some instruments and appliances, such as gas governors, is not consumed in the ordinary course of events, and additional quantities are required only when new installations are made. Quick-

[61]Ransome, F. L., *op. cit.*, pp 383–384.

silver is also used as the cathode in certain electrolytic processes for manufacturing chlorine and caustic soda from common salt. The quicksilver combines with metallic sodium as sodium amalgam, which, in the presence of water, immediately reacts and forms metallic mercury and sodium hydrate. Mercuric oxide parts with oxygen readily and is a useful oxidizing agent in certain chemical processes. An important modern utilization of this property is in the manufacture of glacial acetic acid by the oxidation of acetylene.

No important new uses[62] of mercury were reported in 1930, but the feasibility of the use of mercury in power generation was successfully demonstrated, thus creating a relatively new outlet for substantial sales of the metal during the next few years. William LeRoy Emmet, a research engineer of the General Electric Co., first proposed utilizing mercury vapor instead of steam and eventually built an experimental machine. He succeeded in interesting the Hartford (Conn.) Electric Co., which in 1923 installed a 5,000-kw. unit in its Dutch Point station. After working successfully for a time, a boiler head blew out and thousands of dollars worth of mercury was lost. Despite this experience, the same company proceeded to build a larger unit of 10,000-kw. capacity at its South Meadow plant. This new unit, which was started on February 4, 1930, exhibited marked economy in fuel consumption and complete absence of vibration and proved easy to start and operate. Maintenance costs, it is believed, will be less than for standard steam plants, and the new unit has produced as high as 143 kwh. of energy for each 100 pounds of coal burned, as compared with a maximum of 112 kwh. and an average of about 59 kwh. per 100 pounds of coal in steam-power plants owned by American public utilities companies.

A 20,000-kw. mercury-vapor turbine generator is to be installed by the General Electric Co. in a new power plant at Schenectady, where the South Meadow unit was built. This second installation is to be twice as large as the first and will be even more efficient due to increased pressure and temperature. Still a third unit, even larger than the second, was under construction early in 1931 at Kearny, N.J., and the annual report of the Public Service Corporation and subsidiary stations (issued in February, 1931) announced that a 75,000-kw. unit will be installed at the Kearny station next year. The total capacity of the mercury turbines and the auxiliary steam turbines operated with steam produced in the mercury-vapor condensers will then be approximately 95,000-kw. at this one plant.

Translated into mercury requirements, these new installations represent a significant market factor. The mercury in the boiler now operating at the South Meadow plant in Hartford amounts to approximately 2,380 flasks. The Schenectady unit, although twice as large, does not require twice the quantity of metal, but the estimated needs are 250,000 pounds or 3,290 flasks. For the first Kearny unit 270,000 pounds or 3,550 flasks are needed. These two installations, therefore, constitute a demand for more than 6,800 flasks, worth around $750,000.

[62]Tyler, P. M., Mercury: U. S. Bur. Mines, Mineral Resources of the United States, 1930, Part I, Metals, pp. 37-38 1933

This quantity represents more than one-fourth of the apparent domestic consumption of the metal in 1930 and practically one-fifth the total requirements in less abnormal years.

Purposes for which quicksilver was consumed in the United States in 1928:[63]

Use	Number of flasks
Drugs and chemicals:	
Pharmaceuticals	5,493
Dental preparations	362
Chemical preparations	7,486
Seed disinfectants	365
	13,706
Fulminate	6,587
Vermilion	2,450
Felt manufacture	1,720
Amalgamation	453
Electrical apparatus:	
Lamps	1,200
Rectifiers and oscillators	230
Primary and storage batteries, battery zincs, and standard cells	911
Rectifier bulbs and power control switches	215
	2,556
Industrial and control instruments:	
Heat-control devices	204
Compensating clock pendulums	32
Gas pressure and other tank gages	565
Gas analysis apparatus	62
Flow meters	284
Thermometers, barometers, and miscellaneous scientific instruments	146
Industrial control apparatus not definitely specified	1,588
Vacuum pumps	115
	2,996
General laboratory use	628
Manufacture of caustic soda and glacial acetic acid	1,000
Various uses: Emmet boiler, boiler compound, fireworks, wood preservative, antifouling paint, and 100 flasks miscellaneous	2,846
Total	34,942

PRODUCTION

Mercury has fluctuated in price from $25 to $275 per flask of 76 pounds in the United States in the last eighty years. The highest prices were during the World War. The price rose to $105 a flask

[63]Schuette, C. N., Quicksilver: U. S. Bur. Mines, Bull. 335, p. 147, 1931.

during the height of the Comstock mine silver production in 1874. Since 1900, however, the former chief use of mercury, for the amalgamation of gold and silver, has been supplanted very largely by other processes. At the time of writing (July, 1934) quicksilver is being sold in the United States at $75 per flask.

The amount of mercury being used is gradually increasing and the amount used appears to have little relation to the price. The gradual increase in consumption goes on regardless of price fluctuations. If the mercury-vapor engine comes into general use, the amount of mercury needed will greatly increase.

Since October, 1928, the Mercurio Europeo, a cartel formed by the Italian and Spanish producers, has been the leading factor in the world market. The object of this cartel is principally to sustain prices by limiting the amount sold. World stocks at the end of 1930 were equivalent to a year's supply (150,000 flasks or more). The maintaining of high prices encourages competition from other countries and is perhaps the main factor in the increase in United States production the last few years. Thus the United States imports in 1930 were less than during any year since 1913, amounting to only 3725 flasks, valued at $361,810. There were only 13 producing mines in the United States in 1925, but the number increased to 63 in 1929, and to 75 in 1930. United States domestic production, however, fell off 9 per cent in 1930 from what it had been in 1929. At the opening of 1930 mercury sold for $121–$122 per flask. It closed the year at $104–$106. The cartel has certainly not been able to maintain prices in a falling consumption and increase of competition. During the year 1930 the Mercurio Europeo maintained the price of $125 per flask.

Early in 1931 the three Texas producing mines, the Rainbow, the Chisos, and the Study Butte, were producing about 300 flasks per month. The Texas production for 1930 is not exactly known, but probably averaged about 200 flasks per month. Total production of the United States in 1929 was 23,682 flasks and in 1930, 21,553 flasks. California production in 1930—from 40 mines—was 11,451 flasks. Recently, Nevada has supplanted Texas in ranking second in production. World production in 1929 was 161,814 flasks, which fell in 1930 to 107,000 flasks. Spain produced 71,832 flasks in 1929 and only 19,221 (less than the United States) in 1930. Italy produced 57,966 flasks in 1929 and 56,069 flasks in 1930. The Almaden mine in Spain more than doubled its production from 1850 to about 1893; since then it declined to 1927, when it excelled all former records. Its 1929 production was very little less than its 1927. Spain, Italy, the United States, Austria, Mexico, and Russia have been the only important producing nations. The greatest United States production was in 1877. All this came from California and amounted to 79,396 flasks, or more than Almaden has yet produced in a single year.

MINING AND METALLURGY

Quicksilver is mined by open-cut and underground methods. The metal is recovered by roasting, distilling, and condensing in various types of furnaces and retorts. For further information the reader is referred to C. N. Schuette's paper "Quicksilver," U. S. Bur. Mines, Bull. 335, 168 pp., 1931.

PRELIMINARY REPORT ON THE TERLINGUA QUICKSILVER DISTRICT, BREWSTER COUNTY, TEXAS*

CLYDE P. ROSS

INTRODUCTION

The Terlingua district, one of the principal areas in the United States in which quicksilver is mined, was studied in February to April and July and August, 1934, by Clyde P. Ross, of the U. S. Geological Survey, assisted by W. E. Cartwright, C. H. Coldwell, and during parts of the time by J. A. Conners and H. E. Stocking. The work was part of that carried on under allotment from the Public Works Administration. The present summary is prepared at the close of field work. The final report will contain geologic maps, more detailed descriptions, and the results of laboratory studies now in progress.

LOCATION AND EXTENT

Terlingua is in southwestern Brewster County, about 84 miles from the Southern Pacific Railroad at Alpine and somewhat farther from Marathon, through which station most of the freight to and from the district passes. The main Terlingua district, with the town

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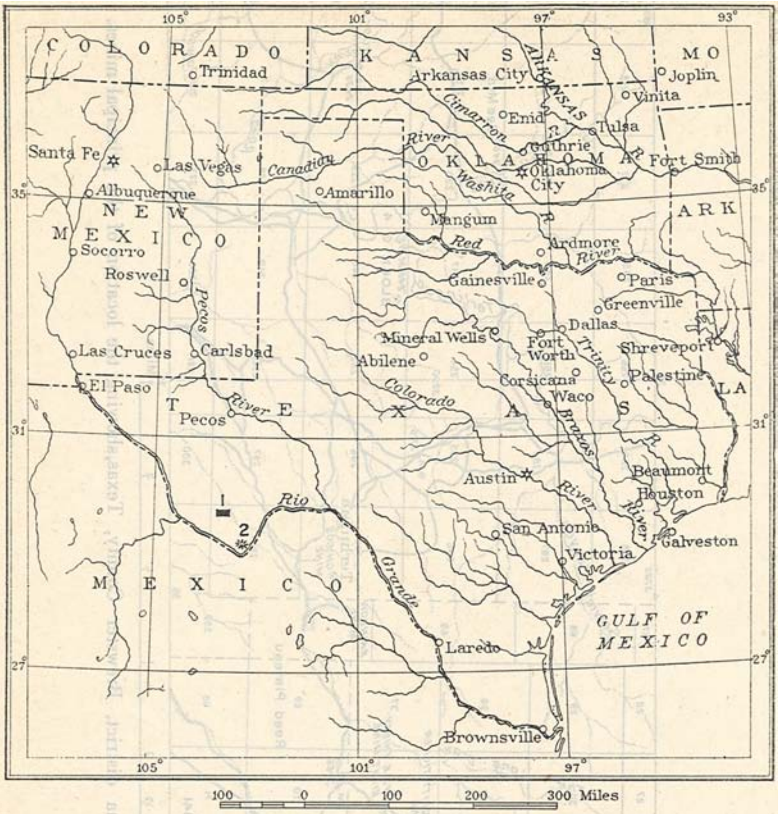

Fig. 27. Outline map of Texas showing the position of the Terlingua district (No. 1) and of Mariscal Mountain (No. 2).

of that name near its center, is a rectangular area about 14 miles long in an east-west direction and 4 miles wide (fig. 28). It contains about 30 mines and prospects. Minor prospects are reported in the Christmas and Chisos Mountain ranges farther east but have never been developed. The only other area in Texas in which quicksilver has been mined is on and near Mariscal Mountain where there is one inactive mine, the Mariscal or Lindsey, and some prospects, one of which was being opened up at the time of visit. The Mariscal mine is over 50 miles by road southeast of Terlingua, but only about 30 miles in a straight line across the southern end of the Chisos Mountains, a range that trends nearly south from a point east of the Terlingua district (fig. 27).

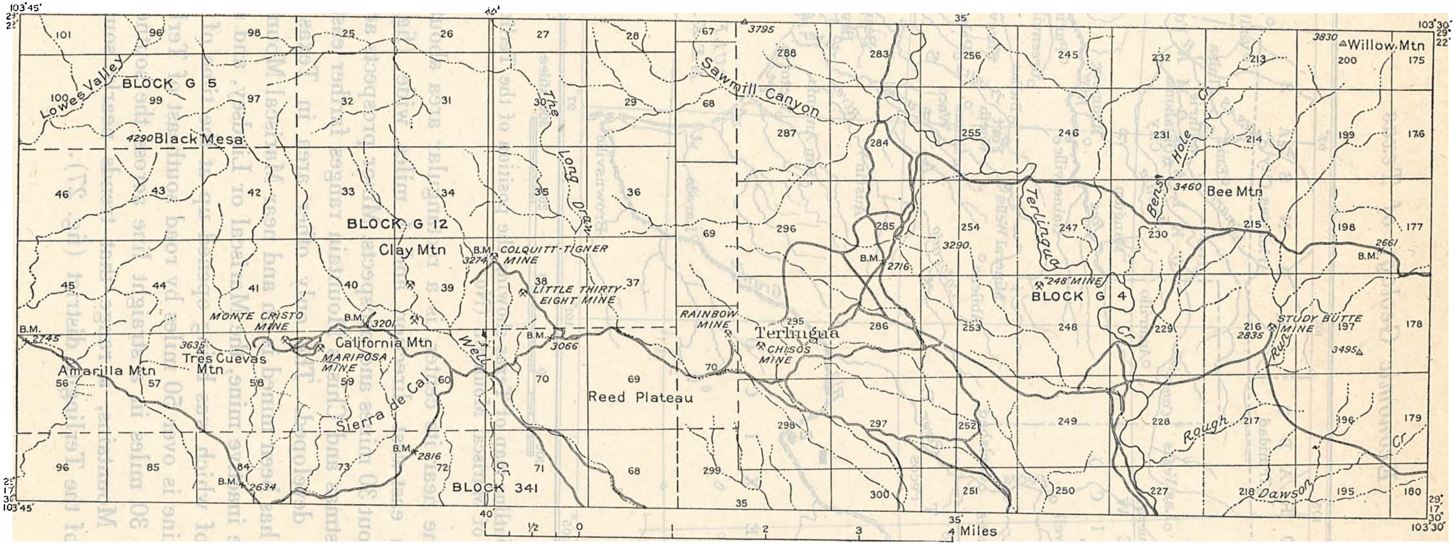

Fig. 28. Sketch map of the Terlingua district, Brewster County, Texas, showing the location of the principal mines.

HISTORY AND PRODUCTION[1]

The presence of quicksilver in the present Terlingua district may have been known as early as 1850 but real development began about 1896 at and near California Mountain (fig. 28). The original settlement called Terlingua was at this locality. The name was transferred to the present settlement farther east when the post office was moved about 1910, when the first production campaign at California Mountain came to an end. Estimates of the production of the Marfa and Mariposa Mining Co., the principal operator during this campaign, range from 17,000 to 30,000 flasks of quicksilver. The production of other operators at this time was not large.

The first discoveries near the present settlement of Terlingua were made about 1900 and the Chisos Mining Co. began work about 1902. This company has been in almost continuous operation ever since and during several periods was the only one active in the district. A little work at the north end of Mariscal Mountain, southeast of the Terlingua district, was done in 1900 to 1902 by Ed. Lindsey.

Operations by two companies at Study Butte, near the east end of the district began in 1903 but production was small and activity here soon ceased for the time.

For several years after 1910 the Chisos Mining Co. was almost the only operator in the district. About 1914 it began to stope a pipe-shaped ore body which proved to be the largest and richest in its history and continued to yield abundantly at least through 1918.[2] The Rainbow mine nearby was reopened in 1916 and operated until 1919. A shaft was sunk about 624 feet but no ore was found. The Mariposa mine was reopened by a new company in 1916 or 1917 and operated until about 1920 with a probable production during this period of roughly 8000 flasks. The property of the two old companies at Study Butte was operated as one mine from 1915 to 1920 with a reported production of about $500,000 worth of quicksilver. The Mariscal mine, under two different managements, produced about 860 flasks in 1917 to 1921 and has been idle since.

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[1]Mainly compiled from data furnished by local mining men, particularly H. E. Perry, Jack Dawson, F. E. Lewis, and W. D. Burcham. The published papers by B. F. Hill, J. A. Udden, and others have also been consulted.

[2]Ransome, F. L., Mineral resources of the United States, 1917, Pt. 1, p. 422, 1919.

A new company reopened the Rainbow mine near Terlingua in 1927, found ore in drifts from the bottom of the shaft, and has been producing since 1929. The Brewster Quicksilver Consolidated reopened the Study Butte mine in 1928 and has continued operation up to the time of visit in 1934, although on a limited scale in recent years. About $400,000 worth of quicksilver is reported to have been produced during this period. In April, 1934, H. C. Slaughter and associates began prospecting on a hitherto untouched lode a short distance north of Mariscal Mountain. Several other companies have been intermittently active in the district since 1925.

The above summary outlines the principal activities in and near the Terlingua district from its discovery through August, 1934. Accurate data on the total production of the Terlingua district are not available. Available estimates of the production of the different properties here and at Mariscal Mountain indicate that the aggregate production through 1934 is somewhere between 130,000 and 200,000 flasks. That is, the area has yielded roughly one-fourth of the total quicksilver produced in the United States since 1899, when active production in Texas began. Since 1902 this limited area has placed Texas second only to California, with its numerous districts, among the quicksilver producing states, except that there have been a few years when the production of Nevada or Oregon or both exceeded that of Texas. The only mines in the United States whose total production exceeds that of the Chisos are about half a dozen in California, all much older.

STRATIFIED ROCKS

There is a thick succession of stratified rocks in and near the Terlingua district. Most are of marine origin but in the upper part of the sequence abundant lava flows are associated with tuffs and sedimentary rocks of probable continental origin. In the vicinity of the quicksilver mines the oldest exposed rocks are Cretaceous but northwest of the Terlingua district marine deposits ranging in age from Cambrian to Carboniferous appear below the Cretaceous strata in a local dome. The circular area about 5 miles in diameter in which the old rocks crop out is known as the Solitario.[3]

[3]Sellards, E. H , Adkins, W. S. and Plummer, F. B., Geology of Texas: Univ. Texas Bull 3232, fig. 9, p. 119 (and numerous references through the text), 1932 [1933].

The oldest Cretaceous strata known near the Terlingua district are beds of Glen Rose age and small amounts of earlier Trinity beds in the Solitario.[4] Strata of Glen Rose age probably also appear at the base of the escarpment near the east end of Santa Helena Canyon on the Rio Grande.[5] Above these is a thick unit composed mainly of rather massive limestone probably best termed Devils River limestone.[6] Most of it is believed to be of Edwards age but strata containing fossils of probable Georgetown age are present at least locally. This unit is widespread in the western part of the Terlingua district and in neighboring areas. Its thickness exceeds 1000 feet.

Above the Devils River limestone is the Del Rio formation, here almost exclusively a dark clay shale. The contact is generally sharp, but there is some interfingering of the limestone and shale. The unit is about as widespread as the Devils River but, in contrast to the broad expanses of the latter, generally crops out in narrow bands at the base of cliffs capped by the overlying Buda limestone. In the Terlingua district the thickness varies from less than 50 feet to nearly 200 feet. In the Mariscal area clayey material possibly belonging to the Del Rio is reported to have been cut in the shaft in the old Mariscal mine, below the workings now accessible. The Del Rio clay is not recognizable in surface exposures in the Mariscal area.

The Buda limestone overlies the Del Rio with a sharp, nearly conformable contact wherever the latter is exposed in the region around Terlingua. It is absent in the part of the area around Mariscal Mountain visited during the present study. The thickness is generally less than 100 feet.

The unit above the Buda limestone consists mainly of calcareous flagstones with some shale, especially in the upper part. It is the formation exposed at the surface around most of the mines in the east half of the Terlingua district and crops out extensively in the region. As mapped during the present study, it corresponds essentially to the Boquillas flags of Udden.[7] Fossils indicate that most

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[4] Sellards, E. H., Adkins, W. S., and Plummer, F. B., *op. cit.*, pp. 297, 305

[5] Cartwright, W. E., Provisional field determination of fossils collected by him.

[6] Udden, J. A., Report on a geological survey of the lands belonging to the New York and Texas Land Co., Ltd., in the upper Rio Grande embayment in Texas: Augustana Library Pub. 6, p. 56, 1907.

[7] Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Texas: Univ. Texas Bull. 93, p. 29, 1907.

of this unit is of about the age of the Eagle Ford formation but the upper part may correspond in age to the lower part of the Austin chalk. In the vicinity of Mariscal Mountain chalky beds with fossils of probable Austin age are distinguishable. The thickness of the unit varies but in most places exceeds 500 feet.

Above the flags is a unit consisting mainly of marly clay. This corresponds approximately to the Terlingua beds of Udden.[8] It crops out in the eastern part of the Terlingua district and over extensive areas to the east and south. In mapping, the lower boundary was placed at the top of the beds containing material amounts of flaggy material. In most places this contact, while gradational, is sufficiently sharp to be easily recognized. The soft, dark calcareous clay composing most of the unit is unmistakable. The greater part of the unit probably corresponds approximately in age to the Taylor marl, with some beds of Austin age at the base. The thickness is probably fully 1000 feet.

Next in succession is the Aguja formation of Adkins[9] whose principal exposures encircle the Chisos Mountains. Cross-bedded sandstone containing concretions constitutes the distinguishing feature of the formation but considerable clay shale and some limestone are also present. Beds of subbituminous coal are common but most are small and contain large amounts of intermixed sediment. Coal from one of the beds of relatively good quality and persistence furnishes producer gas for the Chisos Mining Company's quicksilver reduction plant. The formation in most places is several hundred feet thick.

The formation which probably constitutes the top of the Cretaceous succession in the Terlingua region was named Tornillo clay by Udden.[10] It has much the same distribution as the Aguja and probably grades into it. It is mainly clay, mostly light gray, but locally colored white and different shades of red, purple, and yellow. There are probably over 500 feet of such clays in the area southeast of Study Butte.

Above the Tornillo clay and, at least locally, separated from it by an unconformity, is a thick sequence of light-colored tuffaceous

[8]Udden, J. A., *op. cit.*, pp. 33, 34.

[9]Adkins, W. S., The Mesozoic systems in Texas: Univ. Texas Bull. 3232, Pt. 2, pp. 505–508, 1932 [1933].

[10]Udden, J. A., *op. cit.*, pp. 54–60, 1907.

beds and conglomerates interbedded with lava flows. It is probable that both the flows and the associated clastic beds are of early Tertiary age. Volcanic beds of this general character crop out extensively both east and west of the Terlingua district and remnants in the intervening area indicate that the whole region was originally covered.

Alluvial deposits, in part cemented and probably at least as old as Pleistocene, in part unconsolidated, filling present valleys, are widespread in the region surrounding Terlingua. Within the mining district itself such deposits are generally thin but to the south and east they probably attain thicknesses of hundreds of feet.

INTRUSIVE ROCKS

Small intrusive masses are abundant in and near the eastern part of the Terlingua district and sparsely distributed in its western part. All are more or less fine grained and most are altered. In consequence more laboratory work than has yet been done is required before the character of these rocks is satisfactorily understood. It appears that some are andesitic porphyry and fine-grained quartz diorite and others are basalt. A number, including the one containing ore at Study Butte, are alkali syenite or trachyte, generally with some quartz.

Some are plugs around which the sedimentary strata are sharply bent upward. Others are sill-like in form, but locally, at least, tend to lift and cut through the enclosing beds. There are also persistent, narrow dikes which doubtless follow lines of fracture.

STRUCTURE

In a broad way, a curved anticline extends northwest through the Terlingua region, culminating in the peculiar circular dome of the Solitario. The southwest flank is sharply flexed, locally even slightly overturned. In most of the median portion dips are gentle except where locally disturbed by faulting. The northeast flank is poorly defined and irregular. Dips are moderate except in some of the local zones of flexure and faulting. Part of the irregularity in the structure here results from the numerous small intrusions.

Faulting is one of the conspicuous and peculiar features of the geology of the region around Terlingua. The Mesa de Anguila along the Rio Grande south of the area shown in Figure 28 is a complex of faults, mainly of northwest trend. Another set of northwesterly faults forms a complex, narrow graben along the Long Draw just west of Terlingua. Scattered over the median portion of the anticline from a point west of Terlingua almost to the Solitario are a number of small isolated grabens. The longer sides of the grabens are formed by faults of the dominant northwesterly system but some are terminated or crossed by faults of northeast trend.

Mariscal Mountain is an asymmetric anticline. The axis of the anticline trends somewhat west of north and dips on the western flank are steep. There are minor irregularities and numerous small faults, both reverse and normal. A number of small intrusions, mainly sills, cut the strata.

ORE DEPOSITS

MINERALOGY

The ore deposits of the Terlingua and Mariposa areas differ in many details but the principal hypogene minerals are the same in most. Cinnabar is present in all and may be the only hypogene quicksilver mineral in the deposits of the region. Native quicksilver has been found in several mines, notably the Mariposa and Chisos. Rare oxychlorides and related quicksilver minerals[11] have been found in several places in and near California Hill. Both these and the metallic quicksilver are commonly thought to result from oxidation of cinnabar by weathering agencies.

The principal introduced hypogene gangue mineral in all the deposits is calcite. Much of it is bituminous. Barite and fluorite are sparingly present. Asphaltic material is abundant in the 248 mine and has been found in the Study Butte and others. Zeolites occur in some of the asphalt. Quartz is rare but some prospects in the western part of the Terlingua district show silicification. Kaolinization, and similar alteration, is evident in some of the wall rocks but has not yet been adequately studied. Pyrite, and possibly also marcasite, is generally present in rather small amount.

Jarosite and alunite are abundant in certain outcrops at the Study Butte mine and a different variety of jarosite is reported from the western part of the district.[12] Small amounts of gypsum

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[11]Hillebrand, W. F., and Schaller, W. T., The mercury minerals from Terlingua, Texas: U. S. Geol. Surv. Bull. 405, 174 pp., 1909.

[12]Hillebrand, W. F., and Schaller, W. T., *op. cit.*, p. 17.

are also present in ore near the surface in several mines. All these minerals are doubtless results of surficial alteration.

STRUCTURAL FEATURES

Many of the quicksilver deposits are at or close to the base of the Del Rio clay, in part in the clay, in part in the Devils River limestone below. Clearly the relatively impervious clay tended to trap the rising solutions. Most of the ore in this variety of deposit is confined to a stratigraphic range of about 50 feet but calcite and cinnabar have been found over 200 feet below the base of the Del Rio clay. The ore bodies are more or less closely associated with steep partings trending N. 50°–80° E. Some are associated with the complementary set trending N. 20°–40° W. There is evidence that these partings belong to a regional joint system. They have been locally opened by solution but a large proportion of those in the mines show little or no displacement. Most of the faults in the region have been influenced in trend by the regional joint system but few of the numerous and locally closely spaced parting planes that have aided in localizing ore deposition appear to be fault planes. In some places rolls in the beds near the base of the Del Rio have helped to localize ore deposition.

Nearly all the quicksilver deposits in the part of the district west of the Long Draw exhibit the characteristics sketched above. Near California Mountain there are extensive areas from which the shale has been eroded away, disclosing mineralization in the underlying limestone. For this reason the early discoveries were all made in this part of the district. Similar conditions were found in the Chisos and Rainbow mines, northeast of the Long Draw, where the base of the Del Rio was reached in mining. Most of the rocks at the surface in the vicinity of these two mines belong to the Boquillas and Terlingua formations, as these terms are used in the present paper. These mines were discovered because sufficient cinnabar to encourage prospecting was deposited in the younger rocks by solutions which passed through the Del Rio clay along faults belonging to the set followed by the Long Draw. Details are lacking but it seems that much of the ore mined in the Chisos, especially in the early days, came from fissures and breccia zones related to the complex graben along Long Draw.[13]

[13]Ransome, F. L., Mineral Resources of the United States, 1917, Pt. 1, pp. 422–423, 1919.

Different structural conditions exist in the Study Butte mine. Here most of the ore so far mined is in a rather fine-grained syenitic intrusion which is in part conformable to the bedding of the nearly flat calcareous and argillaceous strata that enclose it. Toward the east it cuts across the beds of a local anticline which appears to have been broken by faults before or during the intrusion. Both anticline and faults may be directly related to the intrusion. The igneous rock is complexly jointed and the ore follows joint partings most of which show opening and small displacements as a result of minor adjustments. Joints with an average trend of roughly N. 65° E. and steep southerly dips are among the most prominent both in surface exposures and throughout the accessible parts of the mine. In the northern part of the mine the principal stoping has been on fissures belonging to this set, which accords in trend with the principal set of joints in the Terlingua region described above. In the southeast part of the mine, where most of the recent development has been done, the nearly vertical ore-bodies trend north to N. 10° E. for the most part. Ore also follows gently inclined partings of variable trend. Throughout the mine mineralization locally follows joint planes of diverse trends.

In the vicinity of Mariscal Mountain all known ore is in the Boquillas formation. In the Slaughter and McDermott prospect recently opened and in some of the minor workings on Mariscal Mountain the ore is on fissures of northeasterly trend which may differ little in genesis from those in the western part of the Terlingua district. In the old Mariscal mine, however, the ore follows a minor thrust fault and some nearly vertical fissures which extend downward into the footwall of the thrust. A small sill in the hanging wall overlies and may have helped to confine the ore.

PRECIOUS STONES

The precious stones known in Texas are agate, amazon stone (microcline), amethyst, beryl, carnelian, chalcedony, jasper, opal, spodumene, topaz, and turquoise. Of these the most important is topaz in clear, transparent, colorless, and beautiful light blue varieties, associated with biotite, tourmaline, sea-green fluorite, smoky quartz, albite, amazon stone, and cassiterite, both in pegmatite veins in granite and as transported placers in the vicinity of

Streeter, Mason County. At Katemcy, Mason County, there are distorted crystals, not of gem quality but associated with the greenish-blue gem, amazon stone.

The different ornamental forms of quartz — agate, amethyst, carnelian, chalcedony, jasper and opal—occur especially in the volcanic rocks of Trans-Pecos Texas. Amethyst is known also from the pre-Cambrian rocks of the Llano uplift. Spodumene is reported from Llano County. Some turquoise has been mined from 6 miles west of Van Horn and was once found by the writer in the volcanic rocks near the Jeff Davis-Brewster county line, north of Alpine. A large crystal of green rutilated quartz was found on the Pierce Smith ranch, near the east end of the Llano-Gillespie county line.

Pearls, although not a mineral product, are found in mussel shells throughout Texas. The discovery of pearls in Nueces River led to the original Spanish settlement of the state.

RARE-EARTH MINERALS

One of the world's greatest deposits of rare-earth minerals is in a pegmatite dike about 100 feet wide forming originally a mound about 40 feet high and between 200 and 250 feet long in the flood plain of Colorado River in Llano County. The pegmatite intrudes coarse porphyritic granite. One vug in the pegmatite, large enough for a man to enter, was lined with smoky quartz crystals, some of the single crystals weighing 1000 pounds or more. There are also huge crystals and masses of feldspar and rather rare, large crystals of fluorite, as well as some bunches of sheets or blades of ilmenite and mica (mostly lepidomelane). The associated rare-earth minerals are compounds of beryllium, cerium, columbium, erbium, lanthanum, neodymium, praseodymium, thorium, uranium, yttrium, and zirconium. Many of the minerals are radioactive. Twenty-nine different minerals have been found in the pegmatite, among which allanite, cyrtolite, gadolinite, yttriolite, rowlandite, fergusonite, polycrase, mackintoshite, thorogumnite, nivenite (uraninite), gummite, antimite, tengerite, lanthanite, and powellite are to be classed among the rarer minerals. These become incandescent on being heated, especially those containing oxides of thorium, beryllium, yttrium, and zirconium. Oxides of the first two elements form the bulk of those used in gas mantles but are too easily volatilized to be used in an electric glower, such as that of the Nernst lamp, in which the oxides of the last two are used.

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Hess, F. L., Minerals of the rare-earth metals at Baringer Hill, Llano County, Texas: U. S. Geol. Surv., Bull. 340, pp. 286–294, 1908.

SILVER AND SILVER ORES

Texas has produced 22,773,944 ounces of silver valued at $15,-359,581. Of the total the Presidio mine at Shafter, Presidio County, has produced 20,282,186 ounces. Most of the remainder has been produced by the Hazel mine (total production nearly $2,000,000) and by neighboring copper-silver prospects of the Van Horn-Allamoore districts of Culberson and Hudspeth counties. A small production has been obtained from the Quitman Mountain district, especially the Bonanza and Alice Ray properties, of Hudspeth County and from the Bird prospect, at the north foot of Altuda Mountain in northwestern Brewster County. Silver is associated with copper in the pre-Cambrian rocks of the Llano uplift of central Texas, and the lead ores in the Upper Cambrian Cap Mountain formation in Blanco and Gillespie counties are stated to carry a small percentage of silver. The mines and prospects of the Quitman Mountains, the Van Horn-Allamoore district, and the pre-Cambrian of the Llano uplift have been described under the sections on copper and zinc.

The Presidio mine is situated on the southeastern plunging nose of the intrusive uplift of the Chinati Mountains at the town of Shafter, 45 miles south-southwest of Marfa. It was discovered about 1880. The Presidio Mining Company treated the ore in a small pan-amalgamation mill from 1883 to 1913. In the last year a cyanide plant was built, which was operated continuously until the mine was closed down on June 30, 1930, at which time silver had become so low in price that it proved impossible to operate at a profit any mine in the United States in which the main value was derived from silver. Up to April, 1926, at which date the property was taken over by the American Metals Company, the mine had produced about 1,150,000 tons of ore averaging about 17 ounces silver to the ton. After underground development demonstrated that important ore reserves still existed, milling was resumed again in

February, 1927. Subsequent to this date the production was approximately 4700 tons of ore per month, of which the yearly average grade varied from 19.7 to 23.2 ounces silver and 20 to 50 cents gold per ton, with 2 to 2.5 per cent lead.

The ore bodies occur in the upper or massive, light gray member of the Cibolo limestone of Upper Permian age, particularly in its lower part. The dip is southeast or south at rates of from 6° to 20°, with an average of about 12°. The whole area is extensively fractured and faulted, many of the fissures containing irregular dikes and small sills of an acid to intermediate fine-grained igneous rock, possibly some of which was intruded after the ore deposits were formed. The dikes strike northeast, northwest, and east. Some of the faults are also post-mineral in age. The most important fault is known as the Mina Grande, striking nearly north-south, with an average downthrow to the west of about 250 feet. Many other faults of varying strikes and with throws of usually less than 100 feet cross the ore bodies. There is a large fault with several hundred feet of throw, about 1000 feet west of the Mina Grande, and still farther west are others, beyond the mine workings.

The ore bodies are rather flat "mantos" or "bankets," generally parallel to bedding planes and situated at several horizons in the upper Cibolo limestone. They are very irregular-trending typical replacement bodies of silver-lead ore, such as are common in areas of anticlinal or closed-fault structures in the "Mountain" limestone of Cretaceous age in the Cordillera of northeastern Mexico.[64] The ore is siliceous, with gangue mainly of quartz with some calcite, dolomite, and iron oxide. The silver occurs as chloride (cerargyrite?) and principally as the sulphide argentite. The lead minerals, all of which carry silver, are galena, cerussite, and locally a little anglesite. The mineralized ore gradually passes into adjacent silicified, honey-combed limestone, which later changes gradually into original, unaltered limestone. Operations of the American Metals Company were concentrated in a section south and west of the old southwestern part of the mine in downthrown faulted blocks formerly erroneously thought to be barren of ore, beyond the faults, and it was the view of these operators that important extensions of ore bodies were to be expected to the west and southwest of present

[64]Baker, C. L., General geology of Catorce mining district [San Luis Potosi, Mexico]: Trans. Amer. Inst. Min. Eng., vol. 66, pp. 42–48, 1922.

mine workings. The deepest workings have ore as rich and as much oxidized as that at the surface. The grade, or tenor, of the ore varies very widely and irregularly. There are many minor faults and slips, many open fissures of varying strikes often as much as 1 foot wide, and underground water courses. Heights of stopes of workable ore vary from 2 to 40 feet, averaging perhaps 10 to 15 feet, and there is bewildering irregularity in the ore content, in places barren or lean ground existing in the midst of workable parts of the mantos. The irregularities are stated to be more pronounced than in the more usual northeastern Mexican replacement lead bodies. The mine has been lately reopened.

There is a silver-lead prospect on Silver Dome Mountain, which is a section of the Rim Rock country situated about 7 miles north of Pinto Canyon, in Presidio County. Although the mineralization is in the Edwards limestone of the Cretaceous, there appears to be considerable similarity with phenomena of the Presidio mine.

The Dick Love prospect on the west side of the Eagle Mountains, southeastern Hudspeth County, has as country rock limestone of Glen Rose Cretaceous age cut by a fault with nearly east-west horizontal slickensides. Black oxides of manganese and iron occur on the outcrop. The gangue is calcite, wad, and iron oxide. The outcrop ore was stated to have run from 1000 to 1600 ounces of silver per ton. Argentiferous galena both crystalline and as a fine amorphous disseminated powder, calamine incrustations of cavity walls, powder-like massicot (lead monoxide), and faint copper stains of malachite and azurite occur. Only a thin stringer persisted at the 60-foot level.

Lead-silver deposits occupying shear zones occur in the intrusive porphyry of the San Antonio Canyon section of the northwest Chinati Mountains. Recently a small shipment of fairly rich silver-lead ore carrying gold has been made from the Solitario also in Presidio County.

The Bird prospect at the north foot of Altuda Mountain, northwestern Brewster County, shipped some rich silver-bearing galena, but for most of the time when silver prices were high enough to afford a chance to develop a mine, the property was idle because of litigation. There are outcrops of syenitic intrusives nearby, the galena occurring as a replacement of Permian limestone.

Most of the silver-lead fissure veins, some of which have also zinc, copper, and gold, now known in Trans-Pecos Texas strike east-west or do not vary more than 20 degrees from that direction. The Hazel mine north of Van Horn, the Dick Love prospect of the western Eagle Mountains, the Bonanza and Alice Ray prospects of the northern Quitman Mountains, three veins in the Chinati Mountains, and the shallow quicksilver deposits of the Sierra del Cal-California Hill area of the Terlingua district are the instances noted by the writer. They are associated with various non-mineralized faults, fissures, and dikes which strike in the same direction. In Eagle and Chinati mountains and the Terlingua district horizontal slickensides show east-west lateral movements, the greatest known horizontal displacements (1 mile and about 2000 feet respectively) being in two cross-faults in the northern Eagle Mountains.

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PRELIMINARY REPORT ON THE SHAFTER MINING DISTRICT, PRESIDIO COUNTY, TEXAS*

CLYDE P. ROSS AND W. E. CARTWRIGHT

INTRODUCTION

The silver-lead mines and prospects in the vicinity of Shafter, Presidio County, Texas, (fig. 29) were examined in May and June, 1934, by C. P. Ross, of the U. S. Geological Survey, assisted by W. E. Cartwright and C. H. Coldwell, under an allotment from the Public Works Administration. This report has been prepared at the end of the field work; only preliminary microscopic studies of the rocks and ores have been made, and the fossils collected have not yet been studied in the laboratory. The section on sedimentary rocks is mainly the work of Mr. Cartwright; the rest of the report was prepared by Mr. Ross.

The reconnaissance map (fig. 30) here presented shows the location of all mines and prospects of consequence in the district

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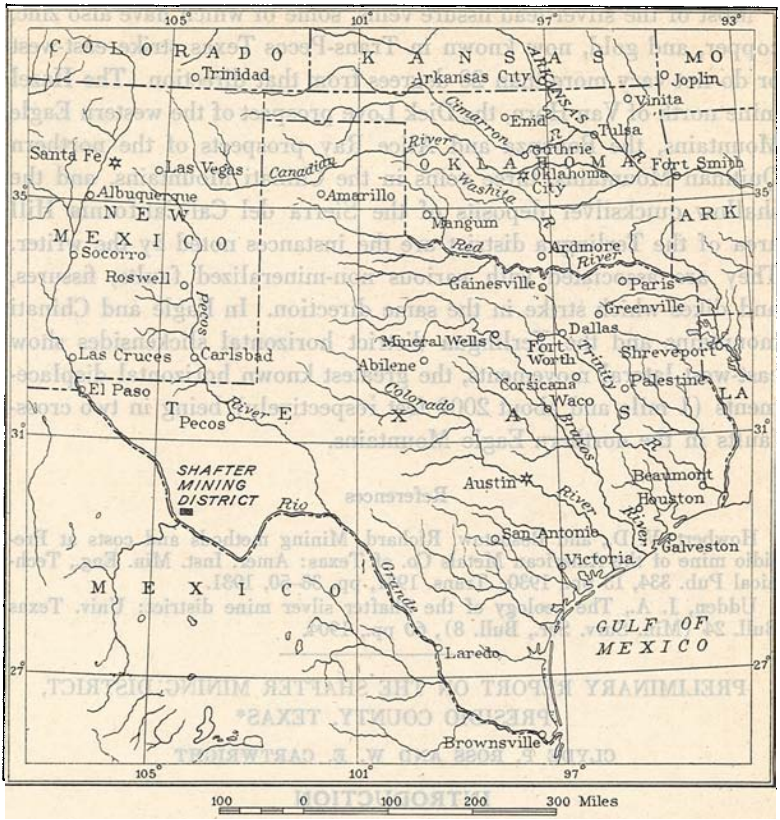

Fig. 29. Sketch map of Texas showing location of the Shafter mining district.

and the broader features of the geology. A detailed geologic and topographic map of about 3 square miles, mainly in sections 2, 5, and 8, Block 8, Houston & Texas Central Railway Co.,[1] including most of the area in which there has been recent development, has been prepared and will be included in the final report. Figure 31 of the present paper is adapted from this map. All the accessible

[1]In the subdivision of the public lands of Texas the larger units are blocks, numbered in various ways. As a rule each block corresponds to a grant of land originally made to some railroad. The blocks are subdivided into numbered sections, which vary greatly in both size and orientation, but many of which cover a square mile, with the sides parallel to the major compass directions.

workings were visited and are briefly described below. More complete descriptions and maps will be presented in the final report.

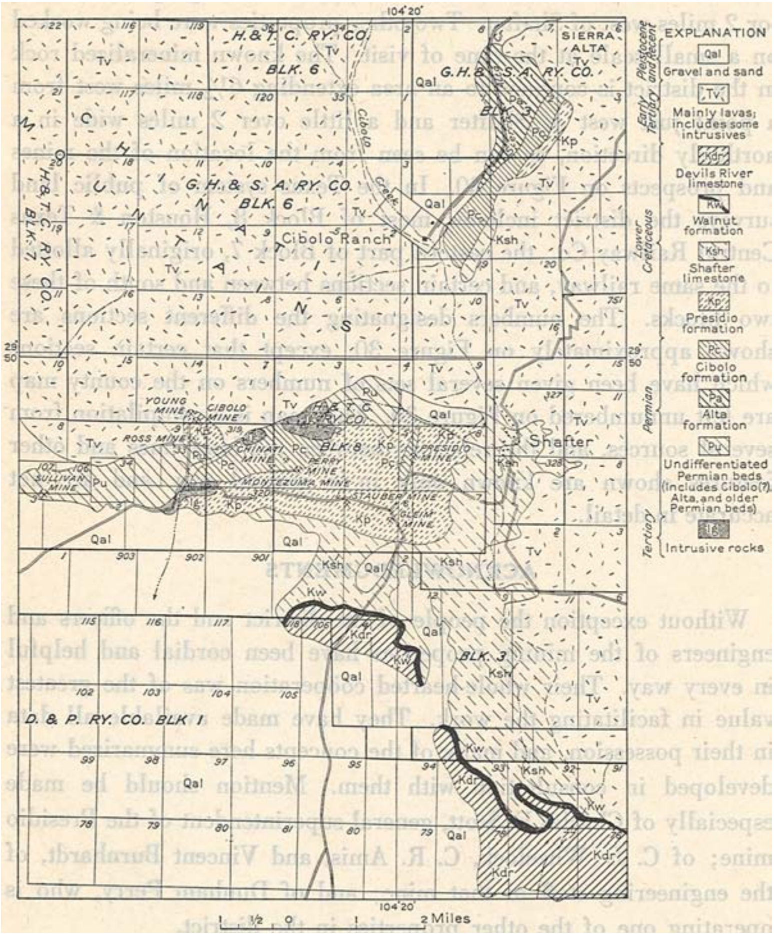

Fig. 30. Reconnaissance geologic map of the region around Shafter, Presidio County, Texas.

LOCATION AND EXTENT

The district is in the south-central part of Presidio County, in the western part of the Big Bend region of southwestern Texas. Shafter, a settlement of nearly 1000 people at the eastern border of the district, is 44 miles by State highway from the Rio Grande at Presidio, which has long been a port of entry from Mexico. The only mine that has yet received large development is the Presidio mine of the American Metal Co. of Texas, whose property extends for 2 miles west of Shafter. Two other properties were being worked on a small scale at the time of visit. The known mineralized rock in the district is confined to an area extending 6½ miles west from a point just west of Shafter and a little over 2 miles wide in a northerly direction, as can be seen from the location of the mines and prospects on Figure 30. In the Texas system of public land surveys the district includes most of Block 8, Houston & Texas Central Railway Co., the eastern part of Block 7, originally allotted to the same railway, and certain sections between and south of these two blocks. The numbers designating the different sections are shown approximately on Figure 30, except that certain sections which have been given several sets of numbers on the county map are left unnumbered on Figure 30. This map is a compilation from several sources, and the relations between the land lines and other features shown are known only in a general way and are not accurate in detail.

ACKNOWLEDGMENTS

Without exception the people of the district and the officers and engineers of the mining properties have been cordial and helpful in every way. Their whole-hearted coöperation was of the greatest value in facilitating the work. They have made available all data in their possession, and many of the concepts here summarized were developed in consultation with them. Mention should be made especially of Charles E. Stott, general superintendent of the Presidio mine; of C. E. Wheelock, C. R. Amis, and Vincent Burnhardt, of the engineering staff of that mine; and of Dunham Perry, who is operating one of the other properties in the district.

SEDIMENTARY ROCKS

In connection with the study of the ore deposits of the Shafter mining district the Permian and Cretaceous sedimentary strata in the vicinity of the Presidio mine were studied in detail. To aid in understanding the stratigraphy of this small area significant exposures in neighboring parts of the Shafter quadrangle were visited.

The data thus obtained are here outlined and compared with those recorded by Udden[2] and Baker.[3] There still remains much that is obscure in the stratigraphy of this part of Texas. The Paleozoic rocks crop out only in isolated areas, and the Cretaceous strata are covered in many places by Tertiary and later deposits. Direct correlation of the beds is therefore difficult.

The table below shows the sedimentary units present in the general vicinity of Shafter. Strata probably belonging to the upper part of the Permian of this region contain all the ore deposits of known economic importance in the Shafter district. The Trinity group of the Lower Cretaceous is also extensively exposed and has been mineralized sporadically within the mining district. Rocks of Fredericksburg and Washita age are present south of the area studied in detail. One of the results of the present study is to show

Stratigraphic Column in the Shafter Region

Age	Group	Formation
Lower Cretaceous	Washita	Buda limestone (?)
		Del Rio clay (?)
	Fredericksburg	Devils River limestone (includes beds corresponding to Georgetown (?), Edwards, and Comanche Peak limestones)
		Walnut formation
	Trinity	Shafter limestone
		Presidio formation
	Unconformity....................	....
Permian	Chinati series of Udden	Cibolo formation
		Alta formation
		Cieneguita beds of Udden

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[2]Udden, J. A., The geology of the Shafter silver mine district, Presidio County, Texas: Univ. Texas Bull. 24, pp. 9–40, 1904.

[3]Baker, C. L., Note on the Permian Chinati series of west Texas: Univ. Texas Bull. 2901, pp. 73-84, 1929.

that the Walnut formation (grouped with the Shafter formation by Udden[4]) can be distinguished in the field. Udden noted that Edwards limestone crops out south of Shafter and grouped with it beds of probable Comanche Peak age below and Georgetown age above. Inspection of some of the exposures of these beds indicates that such a grouping is desirable in this locality, as the differences between the beds seem insufficient for consistent mapping.

Udden also noted that still farther south there are beds which resemble the Del Rio clay and Buda limestone. This locality was not examined, and the Del Rio and Buda are consequently not further discussed in the present paper.

PERMIAN ROCKS

SUBDIVISIONS

The strata of Permian age in the general vicinity of Shafter were termed the "Chinati series" by Udden,[5] after the Chinati Mountains, on whose flanks they are exposed. Udden divided the rocks into three formations, which he named "Cieneguita," "Alta," and "Cibolo," and subdivided these into a total of eight members, as shown in the table below.

The lowest of the three formations took its name from the Cieneguita ranch; the middle formation from Sierra Alta Creek and the hill of the same name; and the highest from Cibolo Creek and the ranch of the same name. The Cieneguita ranch is a short distance north of the area mapped on Figure 30; the map shows the other two localities.

The Permian rocks crop out only in small areas separated by large masses of Cretaceous and later rocks. They vary so greatly in details of lithology and in thickness that only broad and more or less tentative correlations can be made between the subdivisions in the different exposures. The table below summarizes existing data regarding the exposures at the type localities of the three formations. The lithologic descriptions are based mainly on data obtained by W. E. Cartwright. The table also outlines the information obtained by Baker[6] in the basin at the head of Cibolo Creek, and the correlations indicated in the table are those proposed by Baker.

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[4]Udden, J. A., *op. cit.*, pp. 38–40.
[5]Udden, J. A., *op. cit.*, pp. 11–13.
[6]Baker, C. L., *op. cit.*, pp 77–79.

The exposures represented in the table are all in areas several miles north of those containing the known ore deposits. From the data obtained during the present investigation in the vicinity of the different mines and prospects, given in somewhat more detail on following pages, it will be noted that the rocks here differ in numerous respects from those originally described by Udden and Baker, although the broad similarity in stratigraphic relations and fossil content is unquestioned.

As indicated in the table, Udden credits his Chinati series with a total thickness of approximately 6000 feet. Baker estimates the thickness of the upper member exposed in the upper Cibolo basin at 500 feet and says that the zone of sponge spicules immediately below is there only 1 foot thick. His report gives no estimate[7] of the thickness of the two lower units he maps but notes that four of the eight subdivisions recognized by Udden farther south are absent in the headwater basin of Cibolo Creek. Near the mines the thickest section of Permian beds measured aggregates fully 1100 feet. Large thicknesses of lithologically different Permian beds crop out nearby, but it is doubtful if the combined thickness exposed in this vicinity is as great as that recorded by Udden farther north.

THE PERMIAN ROCKS IN THE SHAFTER MINING DISTRICT

Beds that from their lithology, relationships, and fossil content clearly belong to the Permian series crop out in several localities in the Shafter mining district. They have been studied in detail in the isolated exposure at the Presidio mine and also in the hills just north of the Perry mine. Beds that evidently belong to the series are exposed in and near section 4, Block 8, H. & T. C. Ry., and also in and near the eastern part of Block 7, H. & T. C. Ry., but have been examined less carefully. At both of these localities most of the Permian beds are stratigraphically lower than those in the two localities studied in detail.

Beds at the Presidio mine.—The Permian beds at the Presidio mine are overlain unconformably by the basal beds of the Presidio formation. Largely for this reason they are locally believed to

[7]The thicknesses of these two units are as follows: The lower member of flaggy and platy black strata has a thickness of approximately 100 feet and the upper member consisting mainly of limestone but with some dark blue to black chert and much thin-bedded sandstone has a thickness of 385 feet. C. L. Baker.

PERMIAN FORMATIONS IN OR NEAR THE SHAFTER DISTRICT

Formation	Subdivision	Udden's type section	Thickness (feet)	Type locality	Baker's upper Cibolo basin section
Cibolo formation	8. Yellow limestone	Fine- to medium-grained hard yellow dolomitic limestone; thin to medium beds in lower portion; middle and upper portion massive, with local brecciation, chert nodules throughout	650	East bluff of Sierra Alta Creek just above confluence with Cibolo Creek 0.5 mile east of the Cibolo ranch.	Absent.
	7. Thin-bedded zone	Thin-bedded brown, gray, and black, mostly fine-grained limestone, with numerous thin beds, lenses, and concretions of chert and some thin-bedded yellow to brown sandstone. At 0.9 mile southeast of crest of Sierra Alta sandstone is more abundant.	470		Dark-brown to gray coarse-grained and coarsely laminated cherty shale. Rusty-colored thin-bedded micaceous sandstone, interbedded with some shale.
	6. Zone of sponge spicules	Gray, tan, and brown siliceous limestone, with a few thin layers of sandstone. Yellow, brown, and grayish-black thin-bedded limestone and yellow to brown thin-bedded sandstone. Sponge spicules locally abundant, especially in the siliceous and cherty beds; scarce or absent in other beds.	85		One foot of hard, dense siliceous limestone, composed mainly of sponge spicules.
	5. Lower brecciated zone	Essentially a collapse breccia; composed of grayish-white to brown limestone boulders of various sizes; some as large as 6 feet in diameter.	133		Platy brown argillaceous beds at top only. Varicolored chert, occurring in irregular beds, lenses, and concretions, interbedded with a few thin layers of limestone.
	4. Transition beds	Principally gray marl and clay, with some thin to moderately thick beds of sandstone and a few beds of limestone.	100		Absent.
Alta formation	3. Yellow sand	Yellow to brown soft sandstone, with numerous thin to medium beds of hard gray to brown sandstone and a few beds of yellow to brown sandy shale. The hard sandstone beds are relatively abundant in the middle and upper parts of the unit.	1500	Arroyo just south-southwest of the crest of Sierra Alta and 3.1 miles north-northeast of Cibolo ranch.	Medium-bedded quartzites, weathering rusty brown; upper part contains thin layers of grit. Platy argillaceous sandstone. Green muscovitic and arenaceous sandstones and mudstones.
	2. Dark shales	Grayish-black to black paper shale, with yellow to brown hard thin-bedded sandstone intercalated at short intervals.	2000		Absent.
Cieneguita beds of Udden	1. Basal deposits	Consists essentially of dark, almost black shales with some thin beds of chert and medium to thick beds of limestone and conglomerate.	1000	South of Ojo Bonito and 3 miles north of Cibolo ranch.	Absent.

belong to the Cibolo formation, a correlation which agrees with Udden's[8] conclusions. He further suggests that these beds may belong to the uppermost member of the Cibolo formation, the "yellow limestone," which in most places was removed by erosion before the Cretaceous strata were laid down. Unlike the "yellow limestone" at its type locality, most of the unmineralized limestone at the Presidio mine is not dolomitic.

The upper part of the supposed Cibolo beds in the vicinity of the Presidio mine is in general a massive dark gray limestone. Both underground and in outcrops it is exceptional for the bedding to be distinctly visible. In many of the outcrops the gray rock has brownish-yellow mottlings, which have no relation to the mineralization that has affected much of the limestone in the vicinity, as is shown by the presence of similar mottlings in pebbles in the Cretaceous beds. Locally the brown material resembles fragments embedded in gray limestone, but generally the brown merges into the gray. The brown or brownish-yellow material is more magnesian than the gray and may correspond to the yellow dolomitic limestone of the type locality near the Cibolo ranch. In outcrops near the north end of the limestone mass and locally underground there are shaly lenses, but these are generally small and everywhere widely spaced. In the mine workings the massive limestone grades rather abruptly downward into distinctly thin-bedded, locally somewhat shaly limestone. The massive unit is fully 200 feet thick, and the thin-bedded unit must be almost as thick, with its base not yet reached in mining.[9]

Beds north of the Perry mine.—Farther west, in the hills north of the Perry mine, the Permian beds are tilted at about 20°, permitting a thickness of over 1000 feet to be examined—much more than is visible in or near the Presidio mine. These beds lie unconformably beneath the basal Presidio beds and contain fossils which, though not yet thoroughly studied, indicate beyond reasonable doubt that they belong to the Permian series. Because of lithologic changes, laterally, it is difficult to correlate the subdivisions of the Permian, but it is probable that the beds north of the Perry mine correspond broadly to Udden's Cibolo beds.

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[8]Udden, J. A., *op. cit.*, pp. 23, 54.

[9]Howbert, V. D., and Bosustow, Richard, Mining methods and costs at Presidio mine of The American Metal Co. of Texas: Amer. Inst. Min. Eng., Trans 1931, p. 39, 1931.

A section of the strata near the Perry mine is presented in tabular form below, for ready comparison with Udden's and Baker's sections in the table on page 580. The section represents essentially exposures along the gulch that emerges from the hills at the Perry mine and their northward extension across the divide to the point where the Permian rocks give way to Tertiary igneous rocks in the valley beyond. Data from nearby outcrops, however, have been used to supplement the information obtained along the line of section. Most of the thicknesses given are believed to be correct within about 10 per cent, but certain units, notably those above the red shale, exhibit marked lateral variations in thickness within short distances.

Section of the Permian rocks in the area north of the Perry mine.

	Feet
Dark-gray massive, rather pure limestone; contains concretions of chert; thin-bedded near the base	100+
Thin-bedded limestone similar to that below the underlying sill	95
Tertiary andesite sill	45
Dark-gray to black thin-bedded limestone, locally brecciated and with some thin beds of sandstone and shale in the lower portion	185
Dark-red paper shale	70
Thin beds of reddish-pink to reddish-brown siliceous limestone, with intercalated red shale; numerous sponge spicules	15
Dark-red paper shale	40
Brecciated limestone	10
Dark-red paper shale	150
Moderately thick beds of limestone, with red shale partings; some of the limestone beds contain numerous Foraminifera, possibly *Schwagerina*	10—
Dark-red paper shale	150
Tertiary calcic andesite sill	100
Dark thin-bedded shale with numerous beds of black limestone	150+

The massive and thin-bedded limestones can be traced eastward to a point within a short distance of the Presidio mine, except for a short interval occupied by intrusive rock, and undoubtedly are equivalent to the two units exposed there. As indicated in the description of the beds at the Presidio mine, it seems likely that the massive and thin-bedded limestones may correspond to Udden's "yellow limestone." Some of the limestone north of the Perry mine, especially in the thin-bedded portion, weathers yellow, but the massive limestone weathers gray to brown, with local reddish and yellowish-brown magnesian mottlings. On the other hand, it is equally probable that only the massive limestone is to be so correlated and that the thinner beds correspond to part or all of Udden's "thin-bedded zone." In view of Baker's correlations farther north (see p. 580), it is possible that at least part of the red shale north of the Perry mine may correspond to Udden's "thin-bedded zone," and that the rest of the red and black shales and the intercalated limestone beds correspond in a general way to the lower part of the Cibolo formation.

Beds in section 4, Block 8.—In and close to section 4, Block 8, H. & T. C. Ry., there are extensive exposures of the Permian rocks, most of which have been viewed only on reconnaissance trips. A southerly prong of the Permian mass extends into section 5, part of the area mapped in detail. This portion belongs to the upper massive limestone unit and is similar in all respects to that unit as exposed near the Presidio mine (pp. 580, 581). Stratigraphically and topographically below the massive limestone is a thick sequence of thin-bedded limestone, shaly limestone, and shale, with massive limestone reefs in places. The lowest exposed beds are massive conglomerates which underlie shale that contains scattered pebbles. Conglomerate is recorded by Udden[10] only in his Cieneguita beds, the lowest formation in his Chinati series, all of which is now generally considered to be of Permian age.

Beds in the western part of the Shafter district.—Beds that evidently belong to the Permian are extensively exposed in the eastern part of Block 7, H. & T. C. Ry. This area is in the extreme western part of the Shafter mining district, and the only available data on it are those obtained in brief examinations of the prospects.

The undifferentiated Permian beds in this area are overlain by the upper massive limestone unit of the Cibolo formation, which continues without break eastward past the Perry mine. Similar limestone, which may well belong to the same unit, is widespread in the vicinity of the old Sullivan mine, the most westerly in the Shafter district. There are, however, beds of limestone conglomerate here, not seen in any of the exposures of the massive limestone unit farther east, and the bedding throughout is somewhat better marked than is characteristic of that unit.

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[10]Udden, J. A., *op. cit.*, pp. 13, 14.

East of the Sullivan mine there are red hills composed largely of iron-stained and altered quartzite intruded by porphyritic rocks. The stratigraphic relations of the quartzitic beds have not been determined, but they appear to lie well below the massive limestone unit of the Cibolo formation. Lithologically they accord best with the Alta beds described by Udden and Baker.

South of the old Ross mine there are, in upward succession, beds of black limestone crowded with Foraminifera, black fissile shale with limestone ribs, and finally dark limestone. This succession is separated from the western extension of the massive limestone unit of the Cibolo formation by an intrusive mass, but there seems no question that it underlies the massive unit.

AGE

Udden[11] suggested that his Cieneguita and Alta beds were of Upper Pennsylvanian age and that the Cibolo was probably Permian. Böse,[12] from a study of Udden's collection, concluded that the Cibolo formation is of Permian age.

On the basis of field studies at and north of the localities studied by Udden, and on the basis of fossils collected from these localities, Baker[13] concluded that the entire Chinati series of Udden is Permian and correlated the Cibolo formation with the Word formation of the Glass Mountain region.

Sellards[14] correlates Udden's Cieneguita with the Wolfcamp formation of the Glass Mountain region and the Alta formation with the Leonard formation of the same region, and he agrees with Baker that the Cibolo formation is equivalent to the Word formation of the Glass Mountain region. Sellards' correlation is accepted by King.[15] Undoubtedly the three formations are unconformably below and much older than the oldest of the Cretaceous strata locally exposed, and preliminary study by G. H. Girty indicates that the fossils collected during the present investigation are of Permian age.

[11]Udden, J. A., *op. cit.*, pp. 23–25.

[12]Böse, Emil, Contributions to the knowledge of *Richthofenia* in the Permian of west Texas: Univ. Texas Bull. 55, pp. 17–18, 1916.

[13]Baker, C. L., *op. cit.*, pp. 76–79.

[14]Sellards, E. H., The Pre-Paleozoic and Paleozoic systems in Texas: Univ. Texas Bull. 3232, Pt. 1, p. 146, 1932 [1933].

[15]King, P. B., Permian stratigraphy of Trans-Pecos Texas: Bull. Geol. Soc. Amer., vol. 45, p. 783, pl. 107, 1934.

LOWER CRETACEOUS ROCKS

PRESIDIO FORMATION

The lowest of the Cretaceous formations in this region was named the "Presidio formation" by Udden[16] because the principal known exposures are near and southwest of the Presidio mine. Many of these exposures are included in the area mapped in detail during the present investigation. The broader characteristics of the formation are sufficiently uniform so that five subdivisions can be recognized and mapped throughout the area shown on the detailed map. There is, however, considerable lateral variation in both the lithology and the thickness of the different subdivisions. In some localities certain of the basal beds are absent.

The lowest part of the Presidio formation, which attains nearly 100 feet in thickness, consists principally of soft marl, clay, thin-bedded arenaceous limestone, calcareous sandstone, and shell breccia. In some localities a part of these beds is missing; in others they are entirely absent. The overlying unit, which is in places more than 100 feet thick, contains more arenaceous limestone and calcareous sandstone and in addition conglomerate and several beds of marl and shale.

Still higher there are medium-bedded to massive limestone, calcareous sandstone, thin-bedded limestone, in part arenaceous, thin beds of shell breccia composed mainly of *Ostrea* sp., and a fairly massive sandstone, in part calcareous, the whole 75 feet or more in maximum thickness. The middle part of this unit contains a thick yellow to gray limestone with numerous veins of calcite, weathering yellow to yellowish gray, above which is a white sandstone, in part calcareous, which ranges from 5 feet to over 20 feet in thickness. The massive yellow limestone and white sandstone of this unit make it one of the most easily recognizable subdivisions of the formation. Its upper part contains *Orbitulina texana,* marking the lowest stratigraphic horizon at which this foraminifer was found.

Overlying these beds is a group of strata reaching 165 feet in thickness. It is composed mostly of soft sandstone, interbedded with numerous thin layers of arenaceous limestone, hard calcareous sandstone, marl, shale, and two rather thick shell breccias. The breccias constitute the conspicuous and characteristic part of these beds.

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[16]Udden, J. A., *op. cit.*, p. 25.

The uppermost part of this formation consists of rather massive beds of hard arenaceous to fairly pure limestone, with some beds of calcareous sandstone. This unit is resistant to erosion and caps many of the hills in the vicinity of the Presidio mine. It is from 25 to more than 50 feet thick.

Udden[17] states that "lithologically the Presidio beds are identical with R. T. Hill's Travis Peak formation of the Grand Prairie region, and the two are analogous in position." He nevertheless assigned to them the local name "Presidio beds." The present investigation has shown that lithologically and probably paleontologically the Presidio and Travis Peak formations are identical, so that it may eventually prove desirable to drop the local name. So far as field studies of the fossils of the Presidio formation show, the absence of *Dufrenoya* in the Presidio is the main paleontologic difference between it and the Travis Peak formation.

SHAFTER LIMESTONE (RESTRICTED)

The rocks here designated "Shafter limestone" are exposed in and around the town of Shafter and on the banks of Cibolo Creek south of Shafter and form part of a prominent range of hills about 3.2 miles southeast of Shafter and the valley north of the range. They appear to rest unconformably on the Presidio formation.

The Shafter formation as defined by Udden[18] contains rocks of both Trinity and Fredericksburg age. As the younger rocks are susceptible of being mapped separately and are not present close to Shafter, it is here proposed to restrict the name "Shafter" to beds of upper Trinity age.

A section of the Shafter limestone as here restricted was measured at a locality 3 to 3.6 miles southwest of Shafter and about 0.2 mile south of the Stauber prospect and is estimated to be correct within 15 per cent. This section is about 1075 feet thick. Udden[19] on the basis of several partial sections reported a total of about 700 feet of the Shafter, including 80 to 120 feet of strata of Walnut age, not here included in the formation. The following description applies principally to the area where the section was measured.

[17]Udden, J. A., *op. cit.*, p. 30.
[18]Udden, J. A., *op. cit.*, pp. 30–39.
[19]Udden, J. A., *op. cit.*, pp. 31–38.

The lower 200 feet of the Shafter formation consists of limestone beds separated by local thin beds of marl. The next 100 feet consists mostly of limestone, with several sandstone beds, and a few more marl beds than were present in the lower beds. The next 175 feet is almost entirely limestone, with only a few marl partings near the top but with numerous thin marl partings in the lower part. Next above are about 150 feet of alternating beds of limestone and marl, the limestone predominating. Overlying these are alternating beds of limestone, marl, and sandstone, in which the limestone predominates, but the marl beds are thicker and more numerous than below. The next 75 feet consists largely of marl and limestone but contains one bed of clay and one of sandstone. The next 200 feet contains slightly more marl than limestone, and the sandstone beds are also more numerous. The upper 65 feet consists of alternating beds of limestone and marl, with one thin bed of sandstone near the top.

The Shafter formation shows less lateral variation in lithology than the Presidio formation, but several of the sandstone beds thin abruptly and are replaced by limestones.

The Shafter formation as restricted in this paper is lithologically similar to the Glen Rose formation. The general assemblage of fossils from the Shafter, including *Orbitulina texana* and *Porocystis globularis,* does not differ to any great extent from the general assemblage of fossils of the Glen Rose. The principal difference noted in the field is the absence of *Douvilleiceras* and other Glen Rose ammonites in the Shafter formation. If future study of the fossils collected by Cartwright from the Shafter formation confirms the Glen Rose age of the formation as here restricted, it may be desirable to drop the local designation.

DETAILED DESCRIPTION OF THE PRESIDIO AND SHAFTER FORMATIONS

Below are given detailed descriptions by W. E. Cartwright of the Presidio and Shafter formations summarized above. These are presented for use in connection with possible deep exploration, either by mine workings or by drilling, in parts of the region where the Permian rocks are buried under Cretaceous strata. Similar descriptions of the Presidio formation at locality B, Figure 31, and in the East shaft of the Presidio mine, about 800 feet to the southeast, and of several exposures of the Shafter formation have been given by Udden.[20] Comparison of his data with those here presented will show considerable variation in detail—a fact that must be taken into account in any deep exploration.

Section of the Presidio formation at locality A, Figure 31.

	Thickness *Feet*
90. Principally gray to grayish-brown massive hard arenaceous limestone, with some grayish-brown calcareous sandstone and fairly pure limestone. The limestone contains fragments of a rudistid, probably *Toucasia,* and concretions of grayish-tan to brown chert	27.3
89. Badly covered but consisting chiefly of soft calcareous gray to brown sandstone	22.8
88. Alternating beds of rather massive calcareous sandstone and grayish-brown arenaceous limestone, the sandstone predominating	9.5
87. Partly covered but essentially soft thin-bedded grayish-brown calcareous sandstone, with a few beds of gray to brown arenaceous limestone	8.3
86. Covered, probably sandstone	10.3
85. Yellowish-brown marl	4.4
84. Grayish-black medium-grained limestone; weathers light gray	.8
83. Finely laminated grayish-brown nonfossiliferous marl	1.4
82. Gray sandy marl; weathers grayish tan; contains *Orbitulina texana* and *Ostrea* sp.	2.2
81. Medium-grained thin-bedded grayish-black limestone; weathers light gray; contains *Orbitulina texana*	2.0
80. Gray arenaceous nonfossiliferous marl	1.7
79. Grayish-tan medium-grained limestone; weathers brown to grayish brown, and also weathers into more or less rounded nodules. Contains *Orbitulina texana* and *Ostrea* sp.	2.0
78. Dark steel-gray medium-grained thin-bedded limestone, in part arenaceous; weathers brownish-gray	4.8
77. Impure medium-grained dark-gray limestone; weathers dirty brown; contains *Orbitulina texana*	.4
76. Steel-gray thin-bedded medium-grained limestone; weathers rusty-gray; contains *Orbitulina texana*	4.0
75. Covered	15.8
74. Grayish-tan nonfossiliferous marly shale	4.1
73. Covered	6.2
72. Medium-grained gray limestone; weathers into rounded nodules; contains *Orbitulina texana*	1.0

[20]Udden, J. A., *op. cit.*, pp. 25–39.

		Thickness *Feet*
71.	Covered, probably sandstone and marl	7.4
70.	Steel-gray medium-grained limestone with streaks of tan; weathers grayish tan; contains *Orbitulina texana*	.7
69.	Gray to grayish-tan, moderately thin bedded sandy marl	3.0
68.	Gray arenaceous, moderately fine grained limestone; weathers light brown with splotches of yellow; contains fragments of *Ostrea* sp.	.6
67.	Calcareous and argillaceous yellowish-tan sandstone	1.4
66.	Dark-gray medium-grained limestone; weathers light gray; contains *Ostrea* sp.	.4
65.	Soft argillaceous light-tan sandstone; weathers grayish-brown	2.5
64.	Dark-gray limestone; weathers gray with a tinge of brown	.3
63.	Shell breccia, made up mostly of *Ostrea* sp.; matrix consists of soft argillaceous yellow to grayish-tan limestone	7.6
62.	Grayish-brown fine to moderately fine grained thin-bedded limestone; weathers dirty gray to brownish-gray; contains *Ostrea* sp.	7.0
61.	Shell breccia consisting chiefly of broken shells of *Ostrea* but containing several other fossils, including *Orbitulina texana;* matrix consists of soft yellow or tan to grayish-brown somewhat sandy marl	8.2
60.	Medium-grained light-gray to grayish-black limestone; weathers gray to steel-gray; contains *Tylostoma* sp. and *Orbitulina texana*	6.8
59.	Grayish-tan to yellowish-brown calcareous medium-bedded to massive sandstone; weathers tan to brown; contains *Orbitulina texana*	7.1
58.	Medium-grained dark steel-gray thin bedded limestone; weathers gray to grayish-brown; contains numerous *Orbitulina texana*	12.4
57.	Principally arenaceous limestone below and gray to yellowish-white sandstone, in part calcareous, above; the sandstone weathers grayish tan to a glaring white and is one of the most easily recognizable beds in the Presidio formation; contains *Orbitulina texana* and fragments of *Ostrea*	6.1
56.	Grayish-black medium-grained, rather flaky arenaceous limestone; weathers gray; contains *Orbitulina texana*	2.0
55.	Dark grayish-black medium-grained somewhat argillaceous limestone; weathers gray to steel-gray; contains abundant *Orbitulina texana*	4.2
54.	Shell breccia, made up principally of broken *Ostrea* shells; matrix is a yellow to brownish-gray marl	5.4
53.	Dark grayish-black flinty limestone; weathers dark gray to grayish black	3.0

	Thickness *Feet*
52. Fine-grained grayish-brown to dark-gray argillaceous limestone; weathers dark gray and into more or less rounded nodules	2.0
51. Gray to yellow medium- to fine-grained limestone, veined with calcite and in some parts slightly brecciated; usually weathers a pale to a distinct yellow but sometimes gray; beds massive, with a thin bed here and there; fossils scarce or absent	26.5
50. Grayish-brown to steel-gray medium-grained limestone, gray arenaceous limestone, and yellowish-brown calcareous sandstone, the limestone predominating; occurs in medium to massive beds	11.8
49. Medium to moderately fine grained yellowish-brown to grayish-black thin-bedded limestone; contains a few fragments of *Ostrea*	3.0
48. Alternating beds of tan to brown calcareous sandstone and fine-grained gray argillaceous limestone	6.0
47. Alternating beds of grayish-brown arenaceous limestone, dark-gray limestone, and rusty calcareous sandstone; occurs in thin to medium beds	18.0
46. Conglomerate containing angular to rounded pebbles of limestone and quartz; matrix consists of medium to coarse sand grains	8.0
45. Alternating beds of gray to steel-gray medium-grained limestone, in part arenaceous, and soft brown to tan calcareous sandstone, containing fucoids	8.0
44. Coarse grayish-brown nonfossiliferous limestone; weathers yellowish tan	1.1
43. Light-tan shale, thinly laminated	1.5
42. Medium-grained grayish-black limestone; weathers grayish brown	.7
41. Brown shale	1.0
40. Dark-gray medium-grained limestone; weathers gray with tinge of tan	1.1
39. Calcareous grayish-brown sandstone; weathers yellowish-gray	.2
38. Brown shale	1.0
37. Brown to black marl, thinly laminated; contains some bituminous matter	.6
36. Tan to brown nonfossiliferous marl	4.3
35. Dark-gray medium-grained impure limestone; weathers grayish brown; contains fragments of *Ostrea*	.6
34. Dark-gray shale	2.9
33. Brownish-gray, moderately fine grained limestone; weathers yellowish brown	.3
32. Gray marl	.8

	Thickness *Feet*
31. Medium-grained thin-bedded grayish-brown limestone; contains a few fragments of *Ostrea*	4.0
30. Argillaceous and calcareous grayish-brown sandstone; weathers tan to brown	2.4
29. Fine-grained gray argillaceous limestone; weathers light gray	1.6
28. Soft brownish-tan thin-bedded argillaceous sandstone; weathers light brown	3.0
27. Reddish-brown to tan, moderately fine-grained to fine-grained limestone; weathers reddish brown to rusty brown; in part veined with calcite	7.0
26. Gray arenaceous medium-grained limestone; weathers light gray	3.3
25. Soft calcareous tan to brown sandstone; contains some medium-sized pebbles of quartz and worn limestone	3.0
24. Badly covered, probably sandstone	3.0
23. Light-brown calcareous sandstone; weathers light tan	2.0
22. Fine-grained gray limestone; weathers dark gray	3.3
21. Alternating beds of rusty calcareous sandstone and grayish-brown arenaceous limestone, medium to fairly thick bedded	8.3
20. Light-tan to brown calcareous sandstone, in thin to medium beds; some of the beds are slightly conglomeratic	12.5
19. Very fossiliferous grayish-brown moderately coarse-grained limestone in thin to medium beds; contains numerous small pelecypods	11.7
18. Dark-gray, moderately fine-grained, limestone; contains an abundance of fine impurities	.3
17. Shell breccia, made up mostly of *Ostrea;* matrix yellow to brown marl	7.2
16. Brown calcareous sandstone; weathers grayish tan	2.8
15. Medium-grained grayish-black arenaceous limestone; weathers steel-gray	3.2
14. Grayish-black, rather coarse-grained, very fossiliferous limestone	1.7
13. Medium-grained gray limestone; weathers light grayish-brown	2.3
12. Grayish-brown medium-grained arenaceous limestone	.5
11. Light-gray thin-bedded limestone; weathers steel-gray	.7
10. Dark-gray, moderately fine-grained arenaceous limestone; weathers grayish brown	1.1
9. Light-gray calcareous sandstone; weathers grayish brown	1.2
8. Gray fossiliferous calcareous sandstone, in part almost a shell breccia; contains a few disklike concretions and an abundance of small pelecypods	.8
7. Gray, nearly pure limestone, fairly coarse grained, nonfossiliferous; weathers brown	.4

	Thickness *Feet*
6. Grayish-brown sandstone; weathers tan to grayish brown; contains myriads of small pelecypods	1.7
5. Alternating beds of brown calcareous sandstone and gray limestone, in part arenaceous; the sandstone contains a few rounded concretions; both the limestone and the sandstone contain numerous fossils	5.2
4. Moderately fine-grained gray limestone; weathers into somewhat rounded nodules; fossils scarce or absent	8.3
3. Grayish-tan medium-grained arenaceous limestone; weathers tan to light brown	2.8
2. Brown clay, slightly calcareous	4.0
1. Badly covered, but essentially gray to brown clay and marl	12.4

Angular unconformity.

Permian: Yellow limestone (Cibolo formation).

Section of the Shafter limestone 3 to 3.6 miles southwest of Shafter.

	Thickness *Feet*
Walnut formation	80–120
Shafter limestone:	
51. Thin- to thick-bedded steel-gray limestone; weathers light gray to grayish brown; massive beds are hard and contain fragments of *Exogyra texana*	20
50. Pink to reddish-brown, rather coarse-grained limestone	7
49. Massive grayish-brown to gray limestone; weathers yellowish gray to grayish brown; contains fragments of *Exogyra texana*	17
48. Alternating beds of grayish-white limestone and gray to whitish-gray marl. The limestone in part is crowded with *Exogyra texana*	15
47. White or pink to tan medium- to thick-bedded sandstone	11
46. Dioritic sill	13
45. Alternating beds of gray to steel-gray thin-bedded limestone and thin gray to grayish-white marl; slightly more limestone than marl; contains *Exogyra texana, Porocystis globularis,* and other fossils	28
44. Light steel-gray, moderately fine-grained limestone, with a few thin partings of gray marl; the limestone ranges from thin beds below to massive beds in the upper portion; contains fragments of *Exogyra texana*	27
43. Gray to grayish-white marl	12
42. Soft thin- to medium-bedded white or yellowish-white to pink, fairly coarse-grained sandstone; weathers yellowish white to rusty brown	9

	Thickness *Feet*
41. Alternating beds of thin- to medium-bedded gray to grayish-brown limestone that weathers light gray and white to gray marl. The limestone contains *Exogyra texana* and *Orbitulina texana*	24
40. Reddish-brown hard limestone, internally grayish brown	3
39. Yellowish-red to brick-red coarse-grained sandstone; weathers rusty brown to pinkish red	17
38. White to greenish-gray marl	7
37. Alternating beds of thin-bedded, gray limestone with streaks of yellow and whitish-gray marl, also one thin sandstone bed. The limestone contains *Porocystis globularis* and *Exogyra texana*	41
36. Yellowish-brown or pink to brick-red, fairly coarse to medium-grained sandstone	12
35. Grayish-brown marl	5
34. Thin- to medium-bedded, moderately fine-grained light-gray to grayish-tan limestone; weathers in flat to rounded nodules; contains fragments of what appears to be *Exogyra texana*	13
33. Gray to brown shale containing several thin beds of grayish-brown to reddish-brown limestone	8
32. Partly covered, but essentially thin-bedded gray limestone, interbedded with grayish-white marl. The limestone contains *Orbitulina texana*	5
31. Gray fine-grained limestone; weathers light gray; contains a few fragments of *Ostrea*	5
30. Pink or reddish-pink to yellow-brown sandstone, in medium to thick beds; weathers yellowish tan to reddish brown	19
29. Tan to brown soft marl containing one bed of grayish-brown limestone and a gray medium-grained limestone containing *Orbitulina texana*	11
28. Gray to grayish-tan medium-grained limestone containing *Orbitulina texana*	9
27. Whitish-yellow and reddish-brown to rusty-brown thin-bedded sandstone	7
26. Partly covered but consisting essentially of gray to steel-gray thin-bedded limestone with numerous gray marl partings; the limestone contains *Orbitulina texana*	36
25. Gray to grayish-tan limestone and gray marl. The limestone contains *Porocystis globularis*, *Tylostoma* sp., *Orbitulina texana* in abundance, and several unidentified echinoids	19
24. Yellowish-red soft sandstone	2
23. Gray thin-bedded hard limestone; weathers gray with splotches of yellow	7

	Thickness *Feet*
22. Thin- to medium-bedded gray to light-gray limestone; weathers light gray to whitish gray; contains fragments of a rudistid, probably *Toucasia*, and *Orbitulina texana*	18
21. Steel-gray thin-bedded limestone separated by several thin beds of gray marl. The limestone contains *Orbitulina texana*	15
20. Gray to steel-gray thin- to medium-bedded, moderately fine-grained limestone; weathers light gray; contains *Porocystis globularis* and *Orbitulina texana*	34
19. Whitish-gray to gray thin-bedded limestone, in part slightly argillaceous; some of the beds contain numerous *Orbitulina texana*	48
18. Gray to grayish-tan thin to medium thick-bedded limestone; weathers grayish brown	36
17. Steel-gray fine-grained limestone, medium bedded in the upper part, thin bedded below	14
16. Thin-bedded gray to brownish-gray limestone and gray marl; the limestone is moderately fine grained, weathers grayish brown to light gray, and contains a few *Porocystis globularis*	24
15. White to gray marl, with a few thin beds of light-gray limestone	10
14. Grayish-brown to steel-gray fine- to medium-grained limestone; weathers gray or brownish gray to light brown; thin-bedded below, medium-bedded in the middle portion, and thick-bedded, with a few thin beds, in the upper portion. Some of the beds contain *Orbitulina texana* in profusion, and a rudistid, probably *Toucasia*, occurs in several of the harder beds	110
13. Thin-bedded steel-gray limestone, separated by a few marl partings. The limestone contains numerous *Orbitulina texana* and a few *Porocystis globularis*	63
12. Dark-gray, moderately fine-grained medium- to thick-bedded limestone; contains *Orbitulina texana*	15
11. Fine-grained gray thin-bedded limestone; weathers light gray; contains *Orbitulina texana*	16
10. Yellowish-white, fairly hard coarse-grained sandstone; weathers reddish brown to rusty brown	15
9. Principally thin-bedded gray limestone, separated by a few occasional thin partings of gray to grayish-tan marl. The limestone contains *Orbitulina texana* and *Porocystis globularis* in abundance, as well as several other fossils	41
8. Yellowish-red, fairly coarse-grained sandstone; weathers yellowish red to brick-red	20

	Thickness Feet
7. Mostly thin-bedded fossiliferous steel-gray limestone, with a few marl partings. The limestone contains abundant *Porocystis globularis* and *Orbitulina texana* and numerous other fossils	60
6. Gray to grayish-black medium-grained limestone, in thin to medium beds; weathers light gray; some of the thin layers are hard and contain a rudistid, probably *Toucasia*	21
5. Thinly laminated nonfossiliferous gray marl	12
4. Alternating thin-bedded steel-gray fine-grained limestone and grayish-brown marl. The limestone weathers grayish brown	36
3. Grayish-brown to gray marl	6
2. Gray thin-bedded limestone, with a few marl partings	23
1. Medium-bedded hard gray limestone; contains some brown chert	19
	1075

WALNUT FORMATION

As indicated above, it is here proposed for the first time to separate beds of Walnut age from the Shafter formation, although Udden[21] long ago suggested that beds of this age were probably present in the Shafter.

The formation is from 80 to 120 feet thick in the region south of Shafter. It is distinguishable from the underlying Shafter limestone (restricted) by a greater proportion of marl and clay and correspondingly less limestone. In the localities visited sandstone is not present in the Walnut formation. The marls and clays are generally thicker and lighter than those of the Shafter formation, and the limestones are somewhat softer. The hard massive limestone that characterizes certain parts of the Shafter formation is absent in the beds of Walnut age. Thin shell breccias made up mainly of *Exogyra texana*, with a calcareous matrix, are locally present.

The field study of the fossils collected from this formation indicates Walnut age. Among the fossils collected are *Exogyra texana* (abundant), *Gryphaea marcoui, Holectypus planatus, Pseudo-diadema? texana,* an ammonite, not well preserved but belonging to the Engonoceratidae, and others.

[21]Udden, J. A., *op. cit.*, p. 38.

DEVILS RIVER LIMESTONE

Udden[22] explained his use of the term "Edwards" in this area as follows: "It probably includes the Comanche Peak limestone below and the Georgetown above, but the main and middle part is clearly and without the least doubt the western continuation of the Edwards limestone." This expanded usage of the term "Edwards limestone" is not adopted in this report, but the strata thus included are herein designated "Devils River limestone," a name introduced by Udden[23] in 1907, from exposures of the formation on the Devils River in Val Verde County, where it includes rocks of Georgetown and Edwards age. The formation was hurriedly examined by the writers in several localities, all some distance south of the area studied in detail. Unfortunately the very upper part, supposed by Udden to be of Georgetown age, was not seen. The limestones are well exposed at the north end of a deep canyon cut by Cibolo Creek about 6 miles south of Shafter and cap a range of hills about 3 miles southwest of Shafter. Udden[24] estimated the aggregate thickness at not less than 350 feet.

At the localities visited the Devils River strata consist of white to gray generally crystalline limestones. The beds become progressively more massive upward. In the lower 30 to 50 feet of beds *Exogyra texana* is present and flint and rudistids are absent. These features constitute the only observed differences between these beds and those above, which Udden regarded as undoubtedly Edwards. The upper beds contain abundant lenses and concretions of grayish-brown and tan flint. Some of the lenses are over a foot thick. Rudistids occur at several levels but other fossils are rare.

The only evidence for the Comanche Peak age of the lower 30 to 50 feet of this limestone is its stratigraphic position, the presence of *Exogyra texana,* the absence of rudistids and other fossils of Edwards age, and the absence of great amounts of flint. In all other respects this limestone is not distinguishable from the limestone above it.

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[22]Udden, J. A., *op. cit.*, p. 39.

[23]Udden, J. A., Report on a geological survey of the lands belonging to the New York and Texas Land Company, Ltd., in the upper Rio Grande embayment in Texas: Augustana Library Pub. 6, p. 56, 1907.

[24]Udden, J. A., The geology of the Shafter silver mine district, Presidio County, Texas: Univ Texas Bull. 24, p. 39, 1904.

In the localities visited the limestone was overlain by alluvium or formed the cap rock of hills. The extreme upper portion, including the probable Georgetown, was not seen. It is estimated that in these localities there is at least 150 to 200 feet of true Edwards present. Most of the fossils collected from these beds are rudistids, of which *Toucasia* and *Monopleura* were recognized in the field.

IGNEOUS ROCKS

In the immediate vicinity of the Presidio mine the only igneous rocks exposed are narrow basaltic and andesitic dikes. These are all much altered, and some have been partly silicified and replaced by calcite, evidently by the solutions that produced the ore bodies.

Farther west both the Cretaceous and the Permian strata contain basaltic and andesitic sills of more than one kind, which are locally as much as 100 feet thick. They are much less altered than the thin dikes near the Presidio mine, but some of them contain calcite veins, like those associated with the ore deposits. This indicates that they were present when mineralization took place. Some of the basaltic or gabbro porphyry here is so fresh that it may perhaps be of post-mineral age. Certain of the rocks may be as silicic as latite.

As shown on Figure 30, the depression between the Tertiary volcanic strata on the north and the Permian beds on the south is largely floored by intrusive rock, mainly dioritic porphyry. This rock intrudes the lower part of the Permian sequence. It extends under the Tertiary flows with nearly flat upper contact, corresponding closely to the bedding, but the lower contact, if any, is not exposed within the area examined. Calcite veins and mineralized areas in the diorite show that the dioritic rock was present when ore deposition took place. Direct evidence of intrusion was not observed, and it may well be that the intrusive rocks are older than the flows. The relative ages of the larger intrusions and the effusive rocks in this general region have been discussed by Udden[25] and Baker.[26] Both appear to favor the concept that the larger intrusive masses are older than the volcanic rocks, but the evidence they present is not conclusive, and this point remains undecided.

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[25]Udden, J. A., *op. cit.*, pp. 42–44.

[26]Baker, C. L., *op. cit.*, pp. 73–74, 79–82.

STRUCTURE

FOLDS

The broader features of the structure of the region around Shafter are simple, as can be judged from Figure 30. The Permian and Cretaceous sedimentary rocks form an irregular arc bordering the Chinati Mountains, whose shape suggests that they form the southeastern part of a nearly circular dome. The dips are as great as 35°, but in much of the area containing the mines they are commonly less than 20° to the south or southeast. Within the arc lie roughly horizontal Tertiary volcanic strata. The volcanic beds and Quaternary alluvium lap around both ends of the arc and cut through it just north of Shafter. As shown on the geologic map of Texas, the arc of Cretaceous and older strata does not extend far beyond the arc included in Figure 30. Consequently, it is now impossible to determine whether the dome was originally complete or whether the exposed arc is a portion of some more complex structure. However this may be, the Tertiary strata appear to have suffered little folding or faulting. The major deformation in the region took place before their advent.

NORMAL FAULTS

Small normal faults are numerous in the sedimentary beds. The vertical displacement of some of the faults is as much as a few hundred feet, but for most it is 20 feet or less. Most of the normal faults have a considerable horizontal component. Within the area studied in detail (fig. 31) there are no large faults, and at no place in the larger area represented on Figure 30 was any evidence of large-scale faulting obtained. There is a possible exception in the vicinity of the Young mine, where limestone of probable Cretaceous age lies in a depression between a ridge of Permian strata on the south and mountains of Tertiary volcanic rocks on the north. The relations here are obscured by alluvium and Tertiary intrusive rocks.

An idea of the fault pattern in the more developed part of the region can be gained from Figure 31, adapted from the detailed map that will accompany the final report. All igneous masses, alluvium, minor faults, and the subdivisions of the Permian and Cretaceous rocks are omitted on this figure in order to simplify it sufficiently for the present purpose.

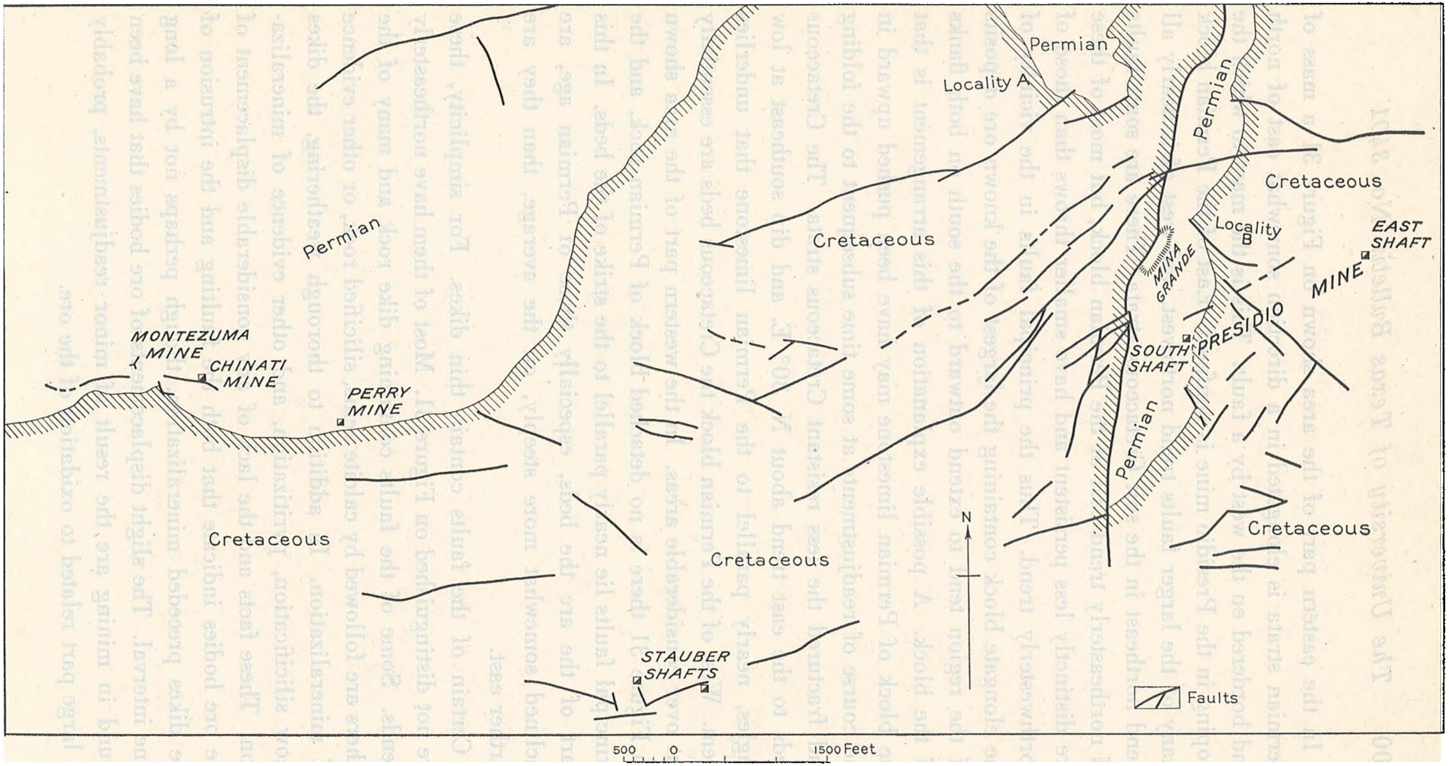

Fig. 31. The fault system in the eastern part of the Shafter mining district, Presidio County, Texas.

In the eastern part of the area shown on Figure 31 a mass of Permian strata is elongated in a direction somewhat east of north and bordered on the west by a fault. This is the mass to which the stoping in the Presidio mine is confined. East of the Permian block many of the larger faults trend northwest, and west of it nearly all trend northeast in the soft Cretaceous strata. There are some faults of northeasterly trend east of the Permian block, but most of these are distinctly less persistent and have smaller throws than those of northwesterly trend. Thus the principal faults in the vicinity of the elongate block containing the largest of the known ore deposits of the region tend to extend outward to the south on both flanks of the block. A possible explanation of this arrangement is that the block of Permian limestone may have been pushed upward in the course of readjustments at some time subsequent to the folding and fractured the less resistant Cretaceous strata. The Cretaceous beds to the east trend about N. 30° E. and dip southeast at low angles, nearly parallel to the Permian limestone that underlies them. West of the Permian block the Cretaceous beds are essentially flat over considerable areas. In the western part of the area shown on Figure 31 there is no detached block of Permian rock, and the principal faults lie nearly parallel to the strike of the beds. In this part of the arc the beds, especially those of Permian age, are inclined somewhat more steeply, on the average, than they are farther east.

Certain of the faults contain thin dikes. For simplicity, these are not distinguished on Figure 31. Most of them have northeasterly trends. Some of the faults containing dike rock and many of the others are followed by calcite veins, silicified rock, or other evidence of mineralization. In addition to thorough weathering, the dikes show silicification, pyritization, and other evidence of mineralization. These facts and the lack of any considerable displacement of the ore bodies indicate that both the faulting and the intrusion of the dikes preceded mineralization, though perhaps not by a long time interval. The slight displacements of ore bodies that have been found in mining are the result of minor readjustments, probably in large part related to oxidation of the ore.

REVERSE FAULTS

Low-angle shear zones inclined opposite to the dip of the beds in a few places close to the Presidio mine record incipient thrusting. Recent underground development is thought to disclose evidence of nearly flat shearing.[27] Reverse faults of notable displacement, however, have not been found in this part of the area. Farther west, in the Chinati and Montezuma mines, a zone of reverse faulting trending roughly east and dipping 30°–60° N. cuts the Permian rocks. One of the more southerly planes of the zone separates a block of Permian limestone above from tilted and somewhat broken Cretaceous strata below. The planes of reverse faulting in this vicinity generally show mineralization, and that in the Chinati mine coincides with the lode that has been stoped. Hence the fracturing and shearing of this sort are of pre-mineral origin and doubtless contributed to the openings that permitted the formation of the ore bodies.

ORE DEPOSITS

GENERAL CHARACTER

All the ore deposits in the district have one feature in common —namely, they have replaced limestone, either along the bedding or along fissures. All contain silver, and in the only large mine, the Presidio, other metals are so sparsely present as to be of value only as by-products. In some of the deposits lead and zinc are relatively more abundant, but even in these the base metals are less abundant than in most ore deposits of this general type. All the ore so far mined is oxidized, although where much lead is present the galena is only partly altered, even close to the surface.

The probability is strong that all the deposits belong to the same period of mineralization. Judged by records of past production, the deposits that are of the greatest economic interest belong to the "manto" type. They are more or less tabular masses on whose shape the bedding planes of the host limestone have exerted a marked influence. Fissures commonly have some effect on the shape of the ore bodies and there are probably all gradations between typical "mantos" and lodes in which the ore consists in part of fissure fillings and in part of replaced fractured limestone along

[27]Stott, C. E., letter of September 6, 1934.

steep fracture zones. The characteristics of the fracture-zone deposits depend upon the nature and attitude of the fissures as well as the character of the containing limestone. Lead and zinc tend to be more plentiful in such fracture zones than in the mantos. A third kind of deposit includes clean-cut fissures filled with coarse vein calcite. The calcite veins themselves are largely barren. However, as will be shown below, these veins are closely related to the ore deposits of the manto and fracture-zone types. A fourth type is characterized by silicified rock and abundant hematite. Deposits of this sort are reported to contain gold and silver and locally lead. They have replaced both sedimentary and igneous rocks, in part along fissures. Turquoise is reported to have been noted in association with such deposits. The only known representatives of this type are in the extreme western part of the district. They have received meager development, and little is known about them.

So far as revealed by present development, nearly all the mantos and most of the mineralized fracture zones are in the Cibolo formation. The principal known ore bodies are confined to a narrow stratigraphic range in the upper part of this formation. The calcite veins cut most of the rocks present in the district and are especially plentiful in the Presidio beds. The deposits with specular hematite are in undetermined parts of the Permian strata or in intrusive rocks. Ore deposition was later than the deposition of the Presidio beds and later than most of the fracturing and igneous intrusion in the district.

PRESENT DEVELOPMENT

The location of all places where there has been any development in the Shafter district is shown on Figure 30. Of these, the Presidio mine, in the eastern part of the district, has been in operation, with short interruptions, since 1880. The principal period of inactivity was from July, 1930, to January, 1934. The mine contains over 40 miles of drifts and crosscuts and has a maximum depth of 700 feet. Stoping extends irregularly but almost continuously through a zone that trends about N. 60° E. for 4000 feet and has a maximum width of about 1500 feet. The total production through July, 1930, was about 1,335,300 tons of ore averaging somewhat over 17 ounces of silver to the ton.[28] The mine was reopened in January, 1934, and milling was resumed in April. From that time through June the mill handled an average of 4700 tons of ore monthly.

This mine has worked only manto deposits, which are in part modified by fissuring, in the lower part of the upper member of the Cibolo formation.

The Stauber and Gleim mines, south of the Presidio property (fig. 30), were worked in 1926 to 1928 or 1929 but have been shut down since then and are inaccessible. The workings include shafts with a small amount of drifts from each, and some are said to be as much as 300 feet deep. The shafts follow mineralized fissures and calcite veins, which near the collars of the shafts are in the upper part of the Presidio beds. In the western shaft on the Stauber property, at least, limestone of the Cibolo formation was penetrated. Some ore has been found in both the Stauber and Gleim properties.

The Perry mine, to the west, has been in operation on a small scale from 1932 through the time of visit, and several sample shipments of ore have been made from it. Considerable mill equipment was on the property in July, 1934. At that time the shaft was down 120 feet, and there were short drifts and small stopes at vertical intervals of 40 feet along it. The ore follows fracture planes and locally bedding in the uppermost member of the Permian limestone. It carries proportionally more lead and zinc than that of the Presidio mine. At this property one of the calcite veins in the Presidio beds has been explored by trenches, and a small amount of good ore is reported to have been obtained from it.

The Chinati and Montezuma mines, west of the Perry mine, received most of their development about 1901 and 1902. A small smelter at Shafter erected at this time treated lead ore from the Chinati mine. Shipments of oxidized zinc ore were made from both mines about 1910 and during the World War, but they have been idle since then. The Chinati mine has been opened to a depth of about 100 feet on a fissure trending nearly east and dipping 30°–40° N., directly opposite to the attitude of the beds of Permian

[28]Howbert, V. D., and Bosustow, Richard, *op. cit.*, p. 38; Howbert, V. D., and Gray, F. E., Milling methods and costs at Presidio mine of The American Metal Co. of Texas: Amer. Inst. Min. Eng., Technical Pub. 368, pp. 6–8. 1930.

limestone which it cuts. In the Montezuma there are small stopes on two ore bodies in the Permian limestone and numerous minor workings. One of the ore bodies stoped is distinctly a manto. The other is more irregular.

The Ross and Young mines are in the western part of the district (fig. 30). Operations at the Ross began about 1890 and at the Young about 1926. Each was worked for about a year and has been inactive since. The amount of development is slight, but both mines are reported to have shipped small amounts of lead-silver ore, and at the Young property a mill was operated for a short time. In both mines replacement bodies in a limestone of probable Cretaceous age were worked, and in both the workings in part lie in Quaternary sediments that fill openings and caves in the limestone. Some of the ore shipped from the Young property appears to have consisted of boulders of galena found in these poorly consolidated sediments.

The shaft of the Cibolo Mining Co. lies between these two old properties. It was commenced in the spring of 1934 and had a depth of about 60 feet when visited early in June. At a depth of 65 feet water was encountered, and work was temporarily suspended.

Shallow workings are scattered over a considerable area south and southwest of the Ross mine, but no work has been done at any of them for a long time. They explore deposits containing specular hematite, fine-grained quartz, and small amounts of gold, silver, copper, and lead in quartzite, limestone, and altered igneous rock. Turquoise is reported to occur in this part of the district.

STRUCTURAL FEATURES OF THE LODES

The part that structural features have played in the mineralization of the district and in the localization of ore bodies can be adequately discussed only with the aid of more data than can be presented in this preliminary paper. Both the bedding planes of certain limestones and fractures belonging to several systems that are widespread in the area have influenced ore deposition. Even in the Presidio mine, the principal example of the manto type of deposit, the influence of steep fracture planes on the localization of the ore is obvious. In parts of the mine control by fissures has been so dominant that the influence of the bedding planes is perceptible only on close examination. In most stopes both visible fractures and bedding planes are much more numerous and closely spaced than they are in the unaltered limestone at the same stratigraphic horizons immediately beyond the borders of the ore bodies. If this relatively close spacing of partings is largely of pre-mineral origin, as it appears to be, it doubtless aided in the introduction of the mineralizing solutions. At the present stage in the study of the data gathered during this investigation no satisfactory explanation of the localization of the close spacing can be offered.

MINERALOGY

The minerals present in the different lodes are much the same throughout the district, except for the undeveloped deposits in its western part, which contain hematite. The proportions vary, however, and certain of the rarer minerals have been noted only in particular spots. The introduced gangue minerals include dolomite, quartz, and manganiferous calcite. The only metallic minerals known to be of hypogene origin are galena, sphalerite, and a little pyrite, but probably silver sulphides were originally present. The supergene minerals include argentite, cerargyrite, limonite, clay minerals, probably some secondary calcite and quartz, manganese oxides, cerusite, anglesite, smithsonite, jarosite, and locally descloizite. Here and there some copper staining is visible.

Dolomitization was one of the earliest manifestations of mineralizing activity, but it was incomplete and nowhere affected the limestone far beyond the limits of the ore formed later. Dolomite is present in both the mantos and the mineralized fracture zones in Permian limestone.

Nearly all the quartz present forms fine-grained masses that replace the limestone, whether or not the limestone had previously been dolomitized. Silicification was roughly coextensive with the present ore in most lodes in Permian limestone, and evidence of it is locally conspicuous in irregular masses and elongate ribs in fissure zones in the Presidio beds. Probably most of the original metallic minerals were formed during or shortly after the silicification.

Oxidation is so complete that little can be learned regarding the hypogene metallic minerals. Pyrite was fairly abundant. Galena was rare in most parts of the mantos and even where locally conspicuous it cannot have ever been as plentiful as in most similar replacement deposits in limestone. Material containing more than

15 per cent of galena is exceptional and has nowhere been found in large masses. Most of the ore in the Presidio mine contains less than 3 per cent. Sphalerite appears nowhere to have made up more than about 6 per cent of the ore.

The other minerals present require no special comment in this preliminary report, with the exception of the calcite. This mineral occurs in large, irregular masses of coarse crystals in both types of deposits. In most places it cuts across and replaces the siliceous ore in such a way as to indicate that it was one of the last of the hypogene minerals to form. In most of the sharply defined fissure veins in Permian limestone, Cretaceous strata, and intrusive rocks calcite is the only vein filling and commonly the only evidence of mineralization. Some of these calcite veins, however, are more or less rusty from oxidized pyrite. Some are bordered by or pass along the strike into rusty masses of silicified material. Samples of the silicified rock along such veins assayed by the American Metal Co. show as much as 10 ounces of silver to the ton. Exceptionally, as in a vein south of the Perry mine, lead-silver ore occurs in a calcite vein.

FUTURE OF THE DISTRICT

It is remarkable that a district in which mining has been carried on successfully for over 50 years and which is known to have mineral deposits scattered over more than 15 square miles contains only one mine of consequence. This mine (the Presidio) has already produced a large tonnage of silver-lead ore and is likely to continue to be successfully developed, if market conditions permit, for a long time to come. It seems probable that other deposits comparable in value to the Presidio mine exist in the district. There are four possible geologic situations in which such deposits might be looked for.

One, perhaps the least favorable, is in or immediately associated with the numerous calcite veins that cut the Cretaceous strata and are regarded as products of the same period of mineralization that produced the ore of the Presidio mine. Although many veins of this character are known, they have been little developed except in the Gleim and Stauber properties. These workings are reported to have followed the calcite veins exposed at the surface in Cretaceous beds down to the Cibolo formation and to have found low-grade ore in both Cretaceous and Permian rocks. On this account and because most of the veins are narrow and, in surface exposures, show little evidence of valuable minerals, it is unlikely that these veins would repay development, although here and there along them pockets of silver-rich material may well exist. These conclusions accord with the fact that although similar calcite is common in parts of the Presidio mine, closely associated with the ore, it rarely contains significant amounts of silver or lead minerals.

A second possibility is that some of the more massive and purer limestones in the Cretaceous formations may contain undiscovered replacement deposits of value. Most of the Cretaceous beds are obviously so argillaceous or sandy and so thin-bedded as to be unsuitable as host rocks, but some, such as the highest unit in the Presidio formation, are sufficiently pure and massive to be favorable. This and lower units in the Presidio are locally silicified, and the silicified rock contains appreciable amounts of silver. The black limestone at and near the Young mine may belong to this unit. Higher in the Cretaceous sequence there are other limestones that possess favorable features. These are some distance away from the Presidio mine and are covered by Quaternary deposits over large areas. Prescott's dictum[29] that "the first favorable limestone encountered by the ascending mineralizer is often by far the most productive" might be regarded as unfavorable to all the Cretaceous beds, as they all lie above the horizon of the known favorable limestone in the Cibolo formation. However, his qualifying statement, "though, under certain conditions, the last favorable limestone also may be unusually productive," leaves the possibility open that a manto deposit of value may somewhere exist in the Cretaceous strata.

A third place to search for possible new ore bodies is in concealed parts of the same beds in the Cibolo formation as have been proved to contain ore in the Presidio mine. An ore body that lies under Cretaceous sediments or even only a relatively short distance below the surface in areas where the Cibolo beds crop out could easily escape detection by surface prospecting. A manto deposit either at such a horizon or in the Cretaceous beds can best be sought by exploration in areas containing known mineralized fissures, especially where nearby rock exhibits evidence of dolomitization or

[29]Prescott, Basil, The underlying principles of the limestone replacement deposits of the Mexican province: Eng. and Min. Jour., vol. 122, no. 7. p. 247, August 14, 1926.

silicification. The calcite veins in the Cretaceous rocks may prove to have their greatest value as guides to buried deposits in more favorable rocks. As some of the ore in the Presidio mine is associated with altered dikes, the presence of similar dikes may also be a favorable indication.

The fourth chance for future exploration lies in the Permian strata below those developed in the Presidio mine. The prospects in the extreme western part of the district prove that replacement can have occurred in some of the lower limestone and quartzite beds. The limestone here is rather thick-bedded and moderately coarse-grained, not unlike some of that in the Presidio mine.

In summary, the single successful mine in the district has had a long and profitable life. After a pause resulting from world-wide economic conditions active production has been resumed and is likely to continue for a long time. Prospecting in other parts of the district has as yet yielded comparatively small rewards. As mineralization extended as much as 6 miles west of the Presidio mine, it seems probable that somewhere in the district other silver-lead deposits exist, which may be as valuable as those already extracted from the Presidio mine. Deep exploration on an adequate scale, which is necessarily expensive, will be required to determine the existence of such ore bodies.

VERMICULITES

The vermiculites group includes a number of micaceous minerals, all hydrated silicates, some of them closely related to the chlorites but of varying composition. They are alteration products, chiefly of the micas, such as biotite and phlogopite, and retain partly the original micaceous cleavage. Dana[65] says concerning them:

> The laminae in general are soft, pliable, and inelastic; their luster pearly or brown-like, and the color varies from white to yellow and brown. Heated to 100°–110° Centigrade (just above the boiling point of water) or dried over sulphuric acid, most of the vermiculites lose considerable water, up to 10 per cent, which is probably hygroscopic; at 300° Centigrade another portion is often given off; and at a red heat a somewhat larger amount is expelled. Connected with the loss of water upon ignition is the common physical character of exfoliation; some of the kinds especially show this to a marked degree, slowly opening out, when heated gradually, into long worm-like threads. This character has given the name to the group, from the Latin *vermiculari*, to breed

[65]Dana, J. D., Textbook of Mineralogy, p 674, John Wiley and Sons, New York, 4th ed., 1932.

worms. The minerals included can hardly rank as distinct species and only their names can be given here: Jefferisite, vermiculites, culsageeite, kerrite, lennilite, hallite, philadelphite, vaalite, maconite, dudleyite, and pyrosclerite.

Uses have developed for vermiculites in the refining of sugar and syrups, as a substitute for asbestos in insulating materials, also for the manufacture of refractories, and some have been found suitable for clarifying oils, that is, as fuller's earths.

Vermiculites have been found near Kingsland, Llano County, and elsewhere in the area of pre-Cambrian rocks of the Llano uplift of central Texas (Llano, Mason, Burnet, Blanco, and Gillespie counties), especially, perhaps, in areas of mica schists and pegmatites. They may be expected to occur in the igneous rocks of Trans-Pecos Texas (Brewster, Presidio, Jeff Davis, Reeves, Culberson, Hudspeth, and El Paso counties), where in many places the intrusive, volcanic, and metamorphic rocks have been highly altered. No workable deposits are now known in the state.

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Petar, A. V., Vermiculite: U. S. Bur. Mines, Inf. Circ. 6720, 10 pp., 1933.

ZINC MINERALS AND ORES

The total production of zinc in Texas has a value of $106,491, or 1,488,474 pounds, and the Bonanza and Alice Ray mines in the Quitman Mountains have yielded the total amount. The zinc sulphide, sphalerite, occurs with other sulphides of the common metals in the salt domes of the Gulf Coastal Plain. Sphalerite and its oxidation products are known in the Apache Mountains of Culberson County, the Chinati Mountains of Presidio County, and in Burnet County of the Llano uplift. Zinc carbonate ore has been produced from the Chinati mine in Presidio County.

Near or at the surface the oxidized zinc minerals, smithsonite (zinc carbonate) and calamine (zinc silicate), usually occur. These resemble closely various forms of limestone, such as calcite, dolomite, travertine, tufa, or caliche, and for that reason are generally overlooked by ordinary prospectors. Very likely there are a number of zinc deposits yet to be discovered in Texas because no attention has been given to these oxidized minerals.

Quitman Mountains, Hudspeth County.—The Bonanza and Alice Ray prospects occur on the same fissure vein in the northern part of the mountains a short distance south of the road from Etholen to the Southern Pacific well, which road passes through the lowest divide across the Quitman intrusive. The Bonanza prospect is situated at the east foot of the mountains near the head of the broad flat valley. The Alice Ray prospect lies across the divide on the western slope. The two differ in altitude over 500 feet. The vein occupies a sheeted zone with several quartz veins, the main vein of which is from an inch to a foot or more in thickness, striking N. 80° E. and dipping 60 to 65 degrees N. 10° W. The country rock is medium to coarse-grained quartz-syenite-porphyry. The outcrop of the sheeted zone is marked by a pronounced topographic trench. Slickensides are found on the walls of the main vein. The outcrop is marked by gossan-stained quartz. The gangue is quartz which on the vein walls often exhibits large crystalline comb structures and in places an intergrowth of nearly amorphous quartz and pyrite. The ore in the Bonanza prospect near the surface consists of galena, wulfenite, sphalerite, and oxidized copper minerals. Assays of silver in the upper zone ran from 20 to 30 ounces. At greater depth the main ore mineral is brown and black sphalerite, with galena tarnishing purplish, pyrite in both large and small crystals, and chalcopyrite. All these minerals are apparently of the zone of secondary sulphide enrichment, as they occur below the water level, which is about 200 feet beneath the surface. The oxidized zone has a vertical range of about 700 feet. Ore shipped from these two prospects ran 30 per cent or more in lead, 25 to 30 per cent in zinc, 20 to 30 ounces of silver, and traces of gold.

Most of the other prospects of the northern Quitman Mountains exhibit zinc and silver-lead ores with a small amount of copper. These prospects are in or near the contacts between the intrusives and the Cretaceous limestones.

Buck prospect, Apache Mountains, Culberson County.—The following account of this prospect was written by Dr. J. A. Udden:[66]

In the hills about 12 miles north of Boracho, in Culberson County, there is a zinc prospect known as the Buck mine. It is in a deep arroyo draining into a tributary of Coyote Creek. The country rock consists of limestone of the Delaware Mountain formation. Work on the prospect has been desultory, by different people, and at different times. Ore was once packed out on burros

[66]Udden, J. A., The Buck zinc prospect near Boracho, Texas: Min. and Sci. Press. vol. 108, pp. 493–494, 1914.

and shipped to Kansas City. A half carload of this ore was left near the Boracho station. A grab sample of this ore yielded 34 per cent zinc. This ore came from two open cuts, sunk at the point where the first discovery was made on the east side of the arroyo. The largest of these cuts, 1 in the figure,[67] is some 20 by 15 by 10 feet in size, and is about 25 feet above the bed of the arroyo. The other cut, 2, is about 20 yards to the northeast, and lower down. The country rock is a coarse-grained limestone, showing altered and mineralized streaks and cavities and a few small irregular veins, an inch or two in thickness, extending in different directions. Some of the veins are filled with calcite, some with smithsonite of fine and compact texture, and some with ferruginous material. Sphalerite of dark brown color was noted in some of the ore bodies of irregular form, and greenish-yellow sphalerite appears in streaky impregnation in the limestone. The whole has the appearance of a part of a cavernous system in a limestone partly filled by mineralizing solutions, this filling having later in part been dissolved away and to some extent oxidized by the leaching and weathering effects of groundwater. A half-dozen picked samples of the size of walnuts, from the walls of each of these two open cuts, give the following averages of zinc:

	Zinc *Per cent*	Silver *Per cent*
Open cut 1	26.0	None
Open cut 2	26.5	None

A piece of the limestone forming the country rock, taken a few feet from open cut No. 2, gave 2 per cent of zinc.

A hundred yards to the northeast from these cuts, a slope, 3, about 40 feet deep has been sunk on a vertical vein and about 15 feet above this a short tunnel, 4, has been driven on the same vein. This vein is from 1½ to 3 feet wide, bears about north 20° west, is filled with stalactitic calcite, laminated vertically, showing characteristic rippled surfaces of drip-stone and, in places, a transverse fibrous structure. In some places the filling is incomplete, leaving thin, open vertical fissures. The walls of the vein are straight, showing hardly any erosion or etching. The vein extends some distance above the tunnel. Samples taken across the vein in these workings gave the following assays:

	Zinc *Per cent*	Silver *Per cent*
Slope 3	0.5	None
Tunnel 4	1.0	None

A half-mile southeast from these workings, two shafts have been sunk, about 80 yards apart. One of these is some 40 feet deep, the other (to the northeast) 25 feet. These expose, in part, some limestone, some talus-like débris, containing weathered blocks and smaller fragments of limestone, and some sandstone and indurated white and purple clay and silt of Cretaceous age. An elongated patch of brown sandstone of Cretaceous age runs northwest immediately to the west of these shafts, and two other small elongated remnants of

[67]Figure not reproduced

the basal sands of the Cretaceous are to be seen in a straight line between this patch and the two open cuts first described. Picked samples from the dumps of the two shafts contained no zinc.

Evidently the Delaware limestone has been traversed by an irregular series of cavernous openings, having a trend approximately parallel to that of the calcite vein. Owing to these openings, Cretaceous deposits found lodgement in some channels having the same trend, laid bare on the shore of the Cretaceous sea in the limestone. Present erosion has cut below the general level of the Cretaceous base, leaving only a few remnants lodged in the deepest depressions of the older rock. Mineralization of the ground must have taken place before the removal of the upper formation.

Evidently a successful exploration of this prospect will require much underground work to locate ore bodies in old seams, joints, porous layers, and cavernous openings, filled by the agency of the mineralizing solutions. The pockets already found may be merely some small offshoots from a much greater system of ore beds in filled caverns, or they may have been the main deposit. The size of the stalagmite vein and the depressions in the lower formation containing Cretaceous sandstone, suggest the existence of an extensive system of old cavernous openings. The conditions are kin to those existing in the Shafter silver mine, though much less appears on the surface of a cavern system than was the case at Shafter.

This prospect is on a range of hills separated from the Delaware range proper by a valley draining to the east into Coyote Creek. Between this valley and the Texas & Pacific Railroad, which roughly parallels the valley at a distance to the south of from eight to fourteen miles, is an anticline whose axis trends a little north of west and south of east. This anticline forms the range of hills mentioned. The prospect is north of the axis of the anticline and on its west end, which has a higher elevation than the east end. Deep ascending mineralizing currents would naturally collect near the highest point of such a structure, and this is another reason for considering further prospecting here warranted by the natural conditions.

Burnet County.—Sphalerite with fluorite occurs at several places on and near the Frank Thomas farm, in the upper valley of the north fork of Spring Creek, about 7 miles west of Burnet. The mineral occurs in bands in hornblende schist. Galena, pyrite, and molybdenite occur as accessory minerals. A carefully taken sample assayed 7.6 per cent zinc.

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SULPHUR

Large accumulations of sulphur are known in two far-distant areas of Texas, one of which is the Toyah basin in Culberson, Reeves, and Pecos counties of Trans-Pecos Texas and the other the area near the Gulf Coast and the mouths of Brazos and Colorado rivers in Matagorda, Brazoria, Fort Bend, and Wharton counties. In both areas the sulphur is associated with calcium sulphate (both gypsum and anhydrite), rock salt, and limestone.

The sulphur deposits of the Gulf Coast, being very profitable, are extensively worked. Those of Trans-Pecos Texas are subject to the high cost of over 700 miles of railroad transportation to Gulf ports and hence cannot compete with the others, which are within a few miles of seaports. At the present time Texas produces over 80 per cent of the world's sulphur.

The sulphur of the Gulf Coast area occurs in the intrusive plugs or domes of rock salt and anhydrite which have pushed up from below to varying distances from the present surface, through the soft and yielding Cenozoic formations. Sulphur can be produced only from the limestone caps, although the sulphur occurs also in the anhydrite. Of some 200 known salt domes on the Texas-Louisiana Gulf Coast, only 8 have been proved to contain large quantities of sulphur, and in these the richest sulphur is apt to be confined to only a portion of the cap rock. The sulphur in the anhydrite cannot be worked because the rock lacks the requisite porosity. The workable sulphur occurs in the porous limestone. Occasionally it is in a more or less continuous bed, but usually it fills seams, fissures, and cavities, or is disseminated through the porous limestone.

A small amount of sulphur occurs at the surface above one of these plugs at Damon Mound, Brazoria County, and springs of sulphur water are found in the vicinity of many of the domes, but all the profitable sulphur occurs beneath the surface. Noxious gases, petroleum, great flows of underground water, quicksands, and "heaving muds" prevent the sinking of shafts to the sulphur, and the production is, therefore, necessarily from wells.

Sulphur from salt domes is produced by the Frasch process, which consists in pumping large quantities of hot water into the earth for the liquefaction of the sulphur. A hole is drilled through the limestone cap rock to the top of the underlying anhydrite and is cased with a 10-inch pipe. An 8-inch string of pipe with perforations extending about 35 feet from the bottom is inserted inside the casing. A 4-inch string of pipe is run and set on a ring in the 8-inch pipe a short distance from the bottom. A $1\frac{1}{4}$-inch string of pipe is run inside the 4-inch to within about 200 feet of the bottom. Superheated water at a temperature of 330° Fahrenheit and at a pressure of from 125 to 250 pounds per square inch is forced down the space between the 8-inch and 4-inch pipes and penetrates the sulphur-bearing formation through the perforations in the 8-inch. Sulphur melts at 283° Fahrenheit and at 284° becomes almost as fluid as water. The melted sulphur runs to the bottom of the well and is then forced for several hundred feet up the 4-inch pipe by the pressure of the water pumps and the head of water. When sufficient melted sulphur has accumulated, a part of the water flow is discontinued, and air is forced down the $1\frac{1}{4}$-inch pipe at a pressure of about 500 pounds per square inch. The melted sulphur is forced to the surface by the air pressure and is carried by centrifugal pumps through steam-heated lines to storage bins. The storage piles are formed by building bins forty feet in height, from 600 to 1000 feet in length, and 250 feet in width. Into these the sulphur is discharged from the steam-heated lines. When a bin is filled with solidified sulphur the side boards are removed and railroad tracks are laid along the sides. When the sulphur is to be loaded into cars it is broken down by drilling and blasting. Should the block of sulphur catch fire, smothering or blasting will extinguish it. One well is able to remove the sulphur from an area of about one-half acre.

The sulphur in Trans-Pecos Texas occurs in the Castile formation of anhydrite and gypsum and is found both on the surface and underground. It is known in appreciable quantity from north of Fort Stockton to the northeast flank of the Guadalupe Mountains in New Mexico, and small amounts have been found in wells drilled in the Permian basin to the east of Pecos River. The deposits can be studied best, however, in an area in eastern Culberson County extending from Delaware Creek, between Delaware and Willow Springs on the north and a line running 3 miles south of Rustler Springs on the south. There are also some deposits in Reeves County west and northwest of Toyah. In the vicinity of the oil seepage 13 miles northeast of Fort Stockton, Pecos County, sulphur occurs in the gypsum at depths between 40 and 600 feet beneath the surface.

The Trans-Pecos sulphur occurs in and with gypsum. Bituminous matter is associated with it. The water in the sulphur deposits contains hydrogen sulphide in solution. The water of Delaware Spring contains sodium sulphide in solution. Original pebbles of limestone have been altered to gypsum containing sulphur. The sulphur occurs as yellow or green, either massive or crystallized, in seams, layers, and masses, or disseminated through the gypsum, but by far the most of it occurs in gypsite (disintegrated and weathered gypsum, or "gypsum soil") and in alluvial and partly eolian conglomerates, clays, sands, and caliche, all of which are materials mantling the surfaces.

Sulphur is derived from the partial oxidation (combustion) of hydrogen sulphide gas. It is formed as a sublimate in volcanic fumaroles and solfataras. Sulphur in important amounts in sedimentary rocks is associated practically invariably with gypsum or anhydrite and commonly with limestone and bituminous matter or petroleum. Most oil occurring in limestone contains considerable sulphur and hydrogen sulphide gas. Inorganic sulphates, chiefly gypsum, may be reduced to sulphur by organic substances. Sulphur may be deposited by the action of certain bacteria. Upon further oxidation part of the sulphur may be changed to sulphuric acid, which can form gypsum from limestone.

The source of hydrogen sulphide may be either volcanic, or from decay of organic substances, or from the decomposition of sulphides through the agency of organic matter. It is difficult to find a source of hydrogen sulphide adequate for the formation of commercial deposits of sulphur. Thus hydrogen sulphide is common in many underground waters, manifesting itself in countless wells and springs, yet only in Texas and Louisiana, apparently, have really large quantities of sulphur accumulated. The Panuco oil of Mexico is saturated with sulphur and the accompanying gas contains a large amount of hydrogen sulphide. The oil occurs in limestone which has been intruded by igneous rocks. The oil field waters contain considerable ammonium, probably derived from the igneous rocks. The probabilities are that the sulphur in the Panuco oil and the accompanying hydrogen sulphide gas come from the intrusive igneous rocks. Whatever the ultimate origin of hydrogen sulphide may be, it is to be noted that underground waters in all thick limestone formations in Texas and Mexico, which range in age from Cambro-Ordovician to Upper Cretaceous, contain large volumes of this gas. Paul Weaver has calculated that the Potrero del Llano well of the Mexican south fields has yielded, with its 125,000,000 barrels of oil, about 5,000,000 tons of sulphur.

The sulphur deposits of Trans-Pecos Texas and New Mexico extend for a distance of 150 miles along the west flank of the Toyah synclinal basin. On the west flank but near the trough of the syncline, in the Tex Oil Company No. 1 Redmond boring about 2 miles north of Quito section house, Ward County, intrusive augite-diabase was found at depths of 4270 to 4365 feet and from 4580 to 4610 feet beneath the surface. Diabase, probably intrusive, was blown from a well at Jal, New Mexico. Because deep wells are long distances apart in the Toyah basin there are abundant chances for the occurrence of other bodies of intrusive igneous rocks not yet known. Hydrogen sulphide derived from these igneous rocks would travel up the dip westwards to the present sites of the sulphur deposits, in which the gas is still escaping and sulphur is still being formed. It seems almost certain that the Trans-Pecos sulphur is formed by oxidation of hydrogen sulphide, although Dr. J. A. Udden considered the gas came from bituminous material which is plentiful in the Delaware Mountain formation which underlies the sulphur deposits.

On the other hand, in the Gulf Coast salt domes the sulphur is more apt to be derived from the reduction of calcium sulphate, present both as gypsum and anhydrite. Either the action of the oil or of anaerobic bacteria may have accomplished the reduction. Oxidation of hydrogen sulphide would appear to be impossible at the depths at which the sulphur formed.

The salt domes at present producing in Texas are Big Hill in Matagorda County, Bryan Heights and Hoskins Mound in Brazoria County, Long Point in Fort Bend County, and Boling in Wharton County. A small production is being obtained from Palangana Dome in Duval County. Sulphur Dome, Louisiana, the original Gulf Coast producer, where the Frasch process of extraction was developed, is now exhausted.

Quantity and value of sulphur sold in Texas for the years 1929 to 1933 inclusive were as follows:

Year	Tons	Value
1929	2,372,388	$30,841,065
1930	2,558,197	46,047,546
1931	2,129,593	38,332,674
1932	875,946.76	15,767,041.68
1933	1,507,749	27,139,482

In recent years the three Texas companies—the Texas Gulf Sulphur Company, the Freeport Sulphur Company, and the Duval Texas Sulphur Company—have mined more than 99 per cent of the total United States production and about 82 per cent of the world's production of sulphur.

Seventy per cent of the total output of sulphur is used in the manufacture of sulphuric acid. About 30 per cent of the sulphuric acid is used in fertilizer manufacturing, 20 per cent in petroleum refining, 10 per cent in the making of various chemicals, 10 per cent in the preparation of steel in galvanizing and tin-plating, 8 per cent to 10 per cent in storage batteries, 2½ per cent in paints and varnishes, 2½ per cent in high explosives, and over 1 per cent in textiles. Bleaching, dyeing, sugar, photographic, and other industries use smaller quantities. About 16 per cent of the total production of sulphur, in the form of sulphurous acid, is used in the conversion of pulp to paper.

In the manufacture of sulphuric acid, the sulphur is merely burned, supplying its own source of heat and leaving no residue. The sulphur dioxide formed by the burning is changed to sulphur trioxide either by the use of finely divided platinum or vanadium as a catalytic agent or by combination with oxide of nitrogen. Water added to the sulphur trioxide makes sulphuric acid.

Rubber is made by mixing the crude gum with sulphur and heating the mixture to about 286° Fahrenheit. This process of vulcanizing changes the rubber from a soft soluble gum to a tough wear-resisting solid. Considerable sulphur is used in the manufacture of various insecticides and fungicides.

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ROCK SALT

A salt is a compound formed from the union of an acid and a base (alkali). An example is the formation of sodium chloride (NaCl) from the union of hydrochloric (muriatic) acid with the strong alkali, sodium hydroxide (or hydrate NaOH) according to the following equation $HCl + NaOH = NaCl + H_2O$ (water). Common salt, generally simply called salt, is sodium chloride, which, in its natural occurrence is the mineral halite, or rock salt. It is a mineral readily dissolved in about 3 parts of water and is easily recognized by its characteristic taste. It is found usually in cubical crystals but may be massive, granular, or compact and is sometimes columnar. When produced from evaporation of brine the crystals are almost always skeletal cubes or "hopper-shaped" crystals composed of a number of small elongated cubes built up to form a hollow pyramid. The hardness of salt is low (2.5) and its specific gravity is 2.1 to 2.6—in pure crystals 2.164. Salt under pressure "flows" with relative ease, a property accounting for its upward intrusion in salt domes.

Rock salt generally occurs in extensive bedded deposits, associated with gypsum, anhydrite, polyhalite, carnallite, clays, sandstones, and limestones. In the deepest part of the Permian salt basin of New Mexico and Texas rock salt is mixed with potassium chloride, the mineral sylvite, and is then known as sylvanite. It is dissolved by underground waters and brought to the surface in springs, as along the Salt Fork of Brazos River and Salt Croton Creek in northwest Texas and also in the alkali lakes of the Llano Estacado and Pecos Valley.

Rock salt is precipitated upon evaporation of the water from various salt lakes or playas ("dry lakes") and from lagoons, bays, or gulfs in which free and open circulation with the sea is partly inhibited. Thus it is deposited along the shores of Baffins Bay and the Laguna Madre of the south Texas coast, the waters of those lagoons containing also high percentages of gypsum and of magnesium and potash salts. The conditions of salt formation have been discussed more fully in another publication.[68]

Salt was produced in 74 plants by 57 companies in the United States during 1933, the production being from mines, wells, and solar evaporation ponds. The solar evaporation plants now operating produce salt from San Francisco Bay, San Diego Bay, and from the vicinity of Long Beach on the Pacific Coast, from the Caribbean Sea in Puerto Rico, and from desert salt lakes in California and Utah. Rock salt is now mined in Louisiana, Kansas, New York, Michigan, Texas, and New Mexico. Rock salt is mined in Texas at the Hockley salt dome, Harris County, and the Grand Saline salt dome, Van Zandt County. It is produced also from salt well brine at the Palestine dome, Anderson County. It was formerly produced from rock salt beds in wells at Colorado, Mitchell County. A small production of stock and impure salt has come for centuries from the Salt Lakes in the Salt basin in Hudspeth County, from Juan Cardona Lake, in Crane County, from Sal del Rey and La Sal Vieja in Willacy County, very possibly from Laguna Salada, Brooks County, from Baffins Bay in Kleberg and Kennedy counties, and from the Laguna Madre in Kennedy, Willacy, and Cameron counties. It has been obtained by boiling to evaporation salt waters from springs on Steens and Brooks salines, Smith County, and Butler

[68]Baker, C. L., Depositional history of the red beds and saline residues of the Texas Permian: Univ. Texas Bull. 2901, pp. 9-72, 1929.

saline, Freestone County; from a number of salines not connected with salt domes in eastern Texas; from wells on Salt Creek near Graham, Young County; from seepages near Tow, in northeastern Llano County; and elsewhere. The Indians obtained salt from the alkali lakes of the Staked Plains all the way from Garcia Lake, Deaf Smith County, southwards to Pecos River—the two largest of which are Cedar Lake in Gaines County and Shafter Lake in Andrews County.

Many of the deeper underground waters of Texas, especially those associated with oil and gas, contain much higher percentages of salt than ocean water. Some evaporated salt is produced from such water by the Texaco Gulf Products Company at West Tulsa, Oklahoma. The disposal of salt water is a serious problem in many oil fields, and in some instances salt and other chemicals are produced as a means of disposing of such otherwise harmful waters. Solar evaporation plants on Baffins Bay and Laguna Madre will produce salt and even more valuable magnesium and potassium chemicals at very cheap cost although subject to the danger of destruction of plants and dilution of the already highly concentrated lagoon waters by West India hurricanes.

Salt produced by evaporation of brines from wells is made in Kansas, Michigan, New York, Ohio, Oklahoma, Texas, Virginia, and West Virginia. Michigan ranks first in production of salt, New York second, Ohio third, Kansas fourth, and Louisiana fifth. Texas ranked fourth in states in shipments of rock salt in 1933 and thirteenth in shipments of evaporated salt. Texas ranked seventh among the states in salt sold or used by producers in 1933, with a production of 165,603 short tons, valued at $560,085. The total United States production in 1933 was 7,604,972 short tons valued at $22,318,086. Michigan, New York, and Ohio together sold 5,320,000 short tons in 1933.

Salt is a cheap and highly competitive commodity. In order to be profitable a market is essential and the cost of producing salt at a mine must be kept down to about $2.00 per ton. Competition in marketing rock salt is so severe that only a product of exceptional purity is apt to have a ready sale for domestic, preserving, and chemical uses.

Salt is used in large amount for culinary purposes and in the meat-packing, fish-curing, dairying, and other industries to preserve foods from deterioration. Another extensive use is in refrigeration. Some salt is used in chlorination of gold. In ceramics it is used for a glaze on pottery and in enameling and pipe works. Much is used for salting live stock and in curing hides. Some is used in clearing oleomargarine. As brine it is used extensively in the chemical industries in the preparation of soda ash, caustic soda, and various other chemicals with a sodium base. A plant of the Southern Alkali Company at Corpus Christi manufactures these chemicals.

In the real deserts of the world such as the Gobi and the Tarim Basin of Central Asia, the Sahara, the desert of northern Chile, and probably in places in the interior of Australia, stream waters rapidly evaporate, leaving their salt contents as caliche-like incrustations along their channels. In some places considerable deposits of impure salt are thus formed. Considerable amounts of salt are blown inland by prevailing on-shore winds of the trade-winds belts from coastal salt marshes or lagoons. Where the waters of such evaporate, the salt upon drying deflocculates itself as well as the clays and sands of the shore areas. The loose particles are readily picked up by the wind and transported inland. The most famous locality of wind-deposited salt is the salt desert of the Rann of Cutch in India. Much salt is blown inland by the southeast trade wind in the coastal area of south Texas, its source being the lagoons of Baffins Bay and Laguna Madre. The coastal area is floored by the impervious Beaumont or Coast clay on top of which accumulates the wind-transported sands, clays, and salt. The rain leaches the salt from the higher areas and it accumulates by the flow of the water to low depressions without outlet or in bare spaces where the clay surface has been swept clean by the winds. Upon evaporation of the water the salt is left in such depressions as the Laguna Salada, La Sal Vieja, and Sal del Rey. Salt water may be found by digging beneath the sand and clay dunes in some places in this area.

The Permian basin of western Texas contains one of the world's greatest rock salt reserves. The area in Texas is the southeastern part of a great geosynclinal basin occupying also much of western Kansas and Oklahoma and eastern New Mexico to the east of the Cordilleran mountain uplifts. All the Panhandle and Staked Plains of Texas is underlain by thick beds of rock salt which are interbedded with anhydrite, sands, clays, and magnesian limestones.

The thickest accumulation of rock salt in the Permian basin is in its southwestern end in the Toyah basin, where in the deepest parts of the syncline rock salt beds are distributed through a thickness of 4500 feet of sedimentary rock. The thickness of rocks in which rock salt beds are distributed in the deeper parts of the Staked Plains geosyncline is between 2000 and 2500 feet. Underneath the southwestern part of the Staked Plains and a part of the Toyah basin northeast of Pecos River the total thickness of the various beds of rock salt, distributed through interbeds of other rock, is greater than 1000 feet. An extensive area with its eastern border being more or less a straight line from north-central Hardeman County south-southwest to central Tom Green County, which lies in the western part of the eroded plains to the east of the Panhandle and Staked Plains, is underlain likewise by rock salt. Underground waters have leached much of the rock salt along the borders of this last mentioned area and also from the outer rims of the Toyah basin, along Pecos River, in a belt on and just west of the anticlinal uplift of the Winkler-Ward County oil fields and over the area of high structure in central Pecos County.

The second great reserve of rock salt in the state is in the salt domes of interior east Texas and in the coastal belt of south Texas. These domes have been found in the territory extending as far east as beyond Mississippi River and as far southwest as Duval County, Texas. Probably 73 of these salt domes are now known in Texas. They are intrusive, more or less cylindrical stocks of salt, anhydrite, and gypsum which have intruded for thousands of feet through the overlying sediments. In the Humble dome, Harris County, a boring penetrated more than 5000 feet of rock salt without reaching its base. The age of the salt is unknown but it cannot be younger than Cretaceous and may be Permian or perhaps even older Paleozoic. The intrusive action of salt, anhydrite, and gypsum is attributed to their property of mobility or flowage under relatively low pressures. The salt is less heavy than the surrounding materials and therefore rises as a consequence of differentials in underground pressures. The salt domes of the Texas Coastal Plain are listed in Part I of this volume. Their location is shown on Plate I (in pocket). The depth to salt in these domes is variable. In some the salt is very shallow, particularly in some of the interior domes such as Palestine (depth 140 feet) and Grand Saline (depth 238± feet). In others the salt is of medium to great depth. In several of the deep-seated domes salt has not been reached.

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GYPSUM AND ANHYDRITE

Gypsum when pure contains 20.9 per cent by weight of water and 79.1 per cent of calcium sulphate with the chemical formula of $CaSO_4.2H_2O$. Its specific gravity is about 2.3. When free from moisture it weighs between 140 and 150 pounds per cubic foot and will average about 3000 short tons of 2000 pounds each per acre for each foot of thickness of deposit. It is a soft mineral, 2 in the scale of hardness, and is scratched readily by the finger nail. Its color is white; when in pure crystals it is colorless and transparent. Its crystals belong to the monoclinic system, and either tabular or flattened or elongated and needle-like arrowhead shapes are produced by twinned intergrowths of two crystals in reversed position. Crystals can be split readily into thin leaves or sheets parallel to the larger surfaces; the sheets being somewhat flexible but not elastic. These sheets are not elastic like those of mica (isinglass), and gypsum differs from mica in being reduced to a white powder in moderate heat, while mica is notably fireproof. Gypsum is only slightly soluble in pure water, 1 part dissolving in 415 parts of water at freezing point temperature and in 368 parts of water at a temperature of 100.4° Fahrenheit. If sodium or potassium chlorides are present in the water, its solubility is considerably greater. Concentrated acids are poor solvents of gypsum but it dissolves in dilute hydrochloric (muriatic) acid. Gypsum is one of the least resistant of all rock materials to long-continued solvent action of circulating ground waters, it being dissolved more readily than limestone.

The crystals or sheets are known mineralogically as selenite, which is found in veins and in disseminated crystals in clay. These crystals generally do not occur in sufficient quantities to be valuable except for mineral specimens. However, the Loma Blanca, or Gyp Hill, about 6 miles southeast of Falfurrias, in Brooks County, Texas, which is a mound about 50 acres in area and rising to a height of 75 to 100 feet above the Laguna Salada, is composed of large vertically-aligned selenite crystals, the cleavage planes of which show vertical movements and ribbing caused by upward movements. This deposit is known to be at least 1000 feet thick and, except in Nova Scotia, is the nearest large gypsum deposit to a seaport known in the Western Hemisphere. The usual gypsum of commercial value is a bedded rock known as rock or massive gypsum, composed of small, interlocking crystals. Where it is of even texture and of white or delicately tinted color it is called alabaster. Satin spar is a mass of parallel or radiating needle-like fibres of gypsum occurring in veins of gypsum or other rocks.

Gypsite is a secondary, loose, powdery, earthy material generally deposited like caliche by evaporation of spring waters carrying gypsum in solution. It is common in the drier parts of the country from Texas and Kansas westward to near the Pacific coast. Gypsite, when in deposits of sufficient size and purity, is preferred by gypsum manufacturers in Texas, Oklahoma, Kansas, and New Mexico because it is excavated cheaply and requires relatively little grinding. The most extraordinary known gypsite is the White Sands of the Tularosa basin in New Mexico in which it has been heaped up in dunes by the wind similar to ordinary sand dunes.

Anhydrite is calcium sulphate without the water of crystallization. When ground, calcined, and mixed with water it does not immediately harden or set as does gypsum when subjected to the same processes; after a long time, however, it will gradually take up water and crystallize as gypsum. Most of the Texas gypsum, and all that commercially valuable, has been formed by the adding of water (hydration) to original anhydrite beds, as is proved by the gypsum passing into anhydrite at varying depths beneath the surface. The hydration of anhydrite to gypsum increases the volume by 33 per cent and the pressure thus generated produces fracturing, crumbling, buckling, and folding.

Anhydrite crystallizes differently from gypsum, in the orthorhombic system, the crystals having a pseudocubic cleavage. Anhydrite is heavier than gypsum with a specific gravity of 2.9 and a weight of 180 pounds per cubic foot. It is harder than either gypsum or limestone, its hardness being from 3 to 3.5. Anhydrite is only difficultly soluble in dilute hydrochloric acid. Anhydrite can be distinguished readily from gypsum by its greater hardness and weight, in not being so readily soluble in dilute hydrochloric acid, and by its failure to harden or set rapidly when mixed with water after being ground and subjected to a moderate heat. Anhydrite is in places found on the surface in west Texas, particularly in recently-cut stream gorges as, for example, in steep bluffs along the Double Mountain and Salt Forks of Brazos River. Anhydrite and gypsum, like rock salt, will deform easily by flowage under moderate pressure.

Anhydrite is the primary and gypsum the secondary hydrated mineral in probably all occurrences in Texas except in small vein deposits. Caves in the Terlingua mining district of southern Brewster County have fillings of gypsum which may be regarded as primary. With sodium chloride (common salt) present in the solution containing calcium sulphate, anhydrite, and not gypsum, will precipitate if the temperature of the solution is 86° Fahrenheit (30° Centigrade) or higher. Because the temperatures of concentrated solutions of these salines at the deeper levels in all but the shallower bodies of water are apparently considerably higher than the surface temperatures, likely the calcium sulphate is deposited as anhydrite. Also gypsum changes into anhydrite at a temperature of 104° Fahrenheit (near 40° Centigrade), and deposits buried fairly deep under other sediments necessarily would be anhydrite, because the temperature increases downwards into the earth.

Aside from the surface gypsite and gypsum in veins, clays, and cavity fillings, the calcium sulphate deposits in Texas were formed by the concentration to the point of precipitation of waters derived from the ocean upon the evaporation of part of the water. Gypsum may be formed from limestone by action of sulphuric acid according to the reaction $H_2SO_4 + CaCO_3 = CaSO_4 + H_2O + CO_2$. Crystals of gypsum disseminated in clays or filling some veins and cavities may be formed by the decomposition of pyrite (FeS_2) or of possibly other metallic sulphides, which forms sulphuric acid and soluble sulphates, which will form gypsum from any calcium carbonate to which these waters have access. Sulphur springs carrying hydrogen sulphide (H_2S) and sulphurous acid derived from volcanoes have the same action.

It is probable that the calcium sulphate supplied to the oceans, lakes, streams, and springs, with the exception of that derived from solution of already existent calcium sulphate deposits, originates from the alteration of calcium carbonate, either in rocks or in solution, by sulphuric and sulphurous acids, sulphates, and hydrogen sulphide and sulphur dioxide gases. When ocean water is concentrated by evaportaion to 19 per cent of its orig'nal volume, calcium sulphate begins to precipitate out of the solution and nearly four-fifths of it precipitates before the original volume is reduced to 9½ per cent. The remaining one-fifth is precipitated along with 77 per cent of the sodium chloride before the concentration to 3 per cent of the original volume. If sea-water continues to enter the basin subject to evaporation, as it did in the great Permian basin of the Southwest, more calcium sulphate, sodium chloride, and other saline compounds continue to precipitate, provided the concentration of the water in the basins remains sufficiently high.

The largest known calcium sulphate and rock salt deposits in the United States which formed in a lake with no connection with the ocean occur in the sediments of a late Cenozoic lake in the Avawatz Mountains at the extreme south end of Death Valley in California. Salt beds are being deposited now in many "dry lakes" or playas in the Great Basin region surrounding the Avawatz Mountains.

Because calcium sulphate is less soluble than rock salt, it is found both nearer the limits of outcrop and nearer the surface in the Permian basin of western Texas and extends farther east in the eroded plains of north-central Texas and farther to the west and south along the edges of the Toyah basin in Culberson, Reeves, and Pecos counties than does salt. Calcium sulphate occurs in thin beds on the outcrop of the Clear Fork Permian formation in north-central Texas, and in underground borings it has been found in the Wichita formation underlying the Clear Fork. The southern border of the calcium sulphate beds in the Permian basin is in Terrell and Crockett counties; the western border is in Jeff Davis and Culberson counties, although some occurs in northeastern Hudspeth County. Farther north the calcium sulphate beds extend far into New Mexico. Their eastern boundary for practical purposes is the eastern limit of outcrop of the Clear Fork formation which extends south-southeast from the northeast corner of Wilbarger County to the center of the east line of Tom Green County. The extensive beds underlying the Staked Plains and Panhandle and the deeper part of the Toyah basin are mainly anhydrite. Pure laminated anhydrite practically continuous for a thickness of 1164 feet was found in the David Flood diamond core drill boring in Sec. 42, Block 54, State School Lands, in Culberson County, 22 miles west-northwest of the town of Toyah. This is overlain by an additional 100 feet thickness of anhydrite with a small amount of shale, above which there is about 600 feet of anhydrite partly changed to gypsum, the total thickness of calcium sulphate in this boring being about 1875 feet.[69]

Gypsum and anhydrite occur in the Trinity and Fredericksburg divisions of the Cretaceous rocks in their extent diagonally across Texas from the northeast corner to Val Verde County. Borings in the following counties have penetrated anhydrite of Trinity age: Bexar, Caldwell, Fannin, Hill, Freestone, Panola, Parker, Shelby, Travis, Uvalde, Val Verde, and possibly Comanche. Gypsum of Trinity age outcrops in Mills and Travis counties; anhydrite of Fredericksburg (Edwards age) has been found in wells in Maverick County and Edwards gypsum outcrops in Gillespie, Kinney, and Menard counties. The gypsum outcropping 13 miles from Fredericksburg on the Mason road and on the Doss road 3 miles west of the Mason-Fredericksburg highway is sufficiently thick and extensive for profitable exploitation, varying from 7 to at least 10 feet in thickness of the bed.

There is extensive gypsum outcropping in at least four places along the northeast base of the Malone Mountains in Hudspeth County. It is uncertain whether the age of this gypsum is Permian or Trinity Cretaceous; the stratigraphy is complicated greatly by thrusting. It has been quarried at Gypsum or Briggs switch on the Southern Pacific Railroad.

Probably 56 anhydrite and gypsum domes are now known in the coastal section of Texas and 17 additional ones in the east Texas syncline. The probability is that most of the shallow domes, of

[69]Udden, J. A., Laminated anhydrite in Texas: Bull. Geol. Soc. Amer., vol. 35, pp. 347–354, 1924.

most interest from the standpoint of possible utilization of salt, anhydrite, and gypsum, have been discovered, because 7 years ago (1927) 41 of the domes were known already in south Texas and 13 in east Texas. Most of the domes discovered in the last 7 years are deep-seated. The domes are more numerous in the delta of the Brazos, both the largest all-Texas river and the one carrying the greatest load of sediment. The Brazos delta really extends from the lower valley of Trinity River nearly to the valley of the lower Colorado River. It is suggested that either the heavy load of sediment deposited by Brazos River has forced the upward movement under differential gravitative stresses of the salt-anhydrite cylindrical intrusions or that thicker beds of salt and anhydrite underlie the region of the Brazos delta or else that both of these factors have brought about the greater number of domes in the area. The age of the salt and anhydrite in the salt domes cannot be younger than Cretaceous and may be Permian or older.

Gypsum is being deposited at present in the very shallow lagoonal waters of the Laguna Madre and Baffins Bay on the southwest Texas coast. A considerable deposit of coarsely crystalline selenite, with the crystals containing sand grains, was encountered in dredging the 16-foot channel between Brazos Santiago and Point Isabel at the southwest end of the Laguna Madre.

Considerable gypsum is sold as lump or ground crude material. The alabaster variety is used as ornamental and building stone. It was so used very early in history in Mesopotamia and Egypt and later in Greece and Rome. At present statuettes, vases, and novelties are made near Paris, France, and in greater amounts in the Florence-Volterra region in Italy. After the transparent alabaster is carved, it is hardened and made opaque by being placed in cold water and slowly raised to the boiling point. Many of these ornaments are sold as Carrara marble. A factory at Leghorn in Italy produces statuettes, lamp shades, pedestals, vases, and other objects, some of which are colored artificially.

Agricultural plaster constituted the first use for gypsum in the United States. That use has increased in recent years. Tests indicate that cereal crops consume about two-thirds as much sulphur trioxide as phosphorous pentoxide and that some of the legumes, including alfalfa, require as much or more sulphur trioxide. By applying sufficient gypsum or anhydrite to soils depleted of sulphur that necessary element is restored. Indirectly also by reaction with other compounds gypsum operates to release other elements, for instance, potassium from silicates, making them available for plant food. The mechanical effect of gypsum is, moreover, important, loosening up heavy clay soils and making them more absorbent of water and fertilizing substances. The anhydrite and gypsum from the shallower salt domes may possibly be utilized for agricultural plaster.

Gypsum is universally employed to retard the set of cement, sufficient crude gypsum to give the cement about 2 per cent by weight of sulphur trioxide being added to the cement clinker and ground with it. Finely ground gypsum is used in insecticides and in some pharmaceutical compounds. Terra alba, which is white gypsum ground to pass 200 mesh, is used as a paper filler, for school crayons, and in paint.

Most gypsum at present used is calcined to make stucco, plaster-of-Paris, and cement plaster. These are prepared by heating gypsum to about 330° Fahrenheit (165° Centigrade), whereupon it loses three-fourths of its water of crystallization and becomes a hemihydrate, $CaSO_4.\frac{1}{2}H_2O$. Calcined gypsum is used for casts and molds for many scientific, artistic, and commercial purposes, as in dental, chinaware, and porcelain casts. Much is used to imbed plate glass, rocks, and various other materials for the purpose of polishing them. Wall and finishing plasters are made of it, as is also the material called staff, in which it is mixed with some fibre like excelsior to make temporary structures, such as exposition buildings. There are many different types of plaster board, blocks, and tiles made by adding various other materials to the calcined gypsum. In roof and floor construction of steel-framed buildings gypsum is poured. Some gypsum concrete ("structolite") is used to make walls of one- or two-story buildings. A porous acoustical and insulating plaster is made by adding certain chemicals to gypsum plaster and water which produce carbon dioxide, bubbles of which give the set plaster a cellular texture. Hydraulic gypsum, or flooring plaster, is anhydrous and made by heating gypsum to about 1650° Fahrenheit (900° Centigrade). This sets slowly when mixed with water and is tamped to a dense, hard mass, which is very resistant to wear. Keene's cement is prepared by calcining gypsum at temperatures from 900°–1100° Fahrenheit (500°–600° Centigrade). This, like natural anhydrite, has very little setting quality, but a setting agent or catalyzer is provided by immersing in a solution of borax, alum, or aluminum sulphate. It then sets to a dense hard mass which can be polished like marble, which is much used in interior decoration and tile effects, being colored to imitate natural stone.

Crude gypsum produced in the United States in 1933 totaled 1,335,192 short tons, the lowest annual production since 1905. Imports in 1933, mainly from Nova Scotia, were 359,490 tons valued at $373,919. Sales of domestic and imported crude gypsum in 1933 amounted to 491,293 tons, valued at $1,089,100. Sales of manufactured gypsum products, both from domestic and foreign supplies, amounted in 1933 to 1,060,471 tons valued at $14,555,112, an average ton value of $13.73. There were sold or used for building purposes in 1933, 1,011,506 tons of manufactured gypsum products valued at $14,085,071 or 95.4 per cent of total tonnage and 97 per cent of total value. New York, Michigan, Iowa, and Texas lead in mining crude gypsum, Texas ranking fourth with a production of 112,106 tons in 1933. In that year Texas producers sold 17,153 tons of crude gypsum for $41,904 and sold or used 75,032 tons of calcined gypsum valued at $1,016,965, the total value of the production being $1,058,869. The other states producing gypsum in 1933 were Arizona, California, Colorado, Kansas, Montana, Nevada, Ohio, Oklahoma, South Dakota, Utah, Virginia, and Wyoming. New Mexico formerly produced gypsum.

The largest present uses of gypsum are in the manufacture of wall board, base-coat plasters, plaster board, and lath. Other gypsum plaster products used in notable amounts are sanded, finished, and molded plasters, partition tiles, and Keene's cement. Notable recent development has been the grinding and calcining of gypsum in one operation, at only one-fifth to one-sixth the investment cost required for the ordinary kettle process, new types of wall boards, and the manufacture of soluble anhydrite by heating ordinary gypsum in an oven for 3 hours at about 460° Fahrenheit, for a drying agent which may be completely regenerated and reused repeatedly without loss in efficiency.

Gypsum is produced in Texas by the Certain-teed Products Corporation at Acme, Hardeman County; Gulf Gypsum Company near Falfurrias, Brooks County; Texas Cement Plaster Company at

Hamlin, Fisher County; United States Gypsum Company at Sweetwater, Nolan County; and Universal Gypsum and Lime Company at Rotan, Fisher County.

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MISCELLANEOUS MINERALS

Many other minerals occur in Texas, usually in minor amounts. Among these are celestite, chromite, fluorite, garnet, kyanite, mica, molybdenite, oxides of tin, and vesuvianite.

Celestite.—Celestite (strontium sulphate) and some strontianite (strontium carbonate) occur as lining of vugs, geodes, and other cavities, and also in disseminations in the Glen Rose limestone and marls of central Texas, in Lampasas, Burnet, Williamson, Travis, and Somervell counties.

Celestite is a heavy white to bluish mineral, resembling barite, occurring usually in tabular or prismatic orthorhombic crystals or in fibrous, cleavable aggregates. In some cases it resembles fine-grained, crystalline limestone but is heavier. The chief use of strontium is as a hydrate for beet sugar refining, especially in Germany. In the United States it is used mainly as a nitrate to produce "red fire" in fireworks, signals, and flares. In drugs, chemicals, and medicines, the bromide, iodide, chloride, hydroxide, nitrate, carbonate, sulphate, salicylate, and other salts are used. It is used to some extent as a substitute for barite in various fillers and paints, including lithopone. The largest domestic deposits are in the later Cenozoic lake beds of California, Nevada, Arizona, and Utah.

Chromite.—Chromite occurs as nodules, sometimes of considerable size, and in minute crystals in the large serpentine mass in the northeast corner of Gillespie County and also in smaller serpentine masses in southern Llano County. Derived from this bed rock occurrence is chromite in black sand placers in the drainage basins of Cole, Crabapple, and Sandy creeks downstream from the bed rock outcrops.

Chromite is used in the production of stainless steel, in chromium-plating, in which it has largely supplanted nickel and silver, in refractories (bricks, cements, grogs, and patch), in pigments (chrome yellow, chrome orange, and chrome green), and in sodium and potassium bichromates and chromates, as well as in other chemicals. The chief producing countries are Southern Rhodesia, Russia, New Caledonia, Yugoslavia, Turkey, South Africa, India, and Cuba in the order given.

Fluorite.—Fluorite (fluorspar) has been found in Burnet County in central Texas and in the Eagle Mountains of southeastern Hudspeth County and Chinati Mountains of Presidio County in western Trans-Pecos Texas. The Burnet County occurrences are in pre-Cambrian gneisses and schists cut by minor masses of granite and pegmatite in the drainage basin of Spring Creek from 4 to 7 miles west of the town of Burnet. Some sulphides, galena, chalcopyrite, pyrite, molybdenite, and sphalerite are associated with the fluorite. Thin veins occur in the Eagle Mountains, the northwestern Chinati Mountains, and in the Chisos Mountains. Fluorite is used as a flux in the steel and foundry industries, as an ingredient in the enamel and vitrolite industries, for making hydrofluoric acid, for making opal, opaque, and colored glasses, for lenses, and as a synthetic, organic, non-explosive, non-inflammable, and practically non-poisonous refrigerating medium.

Garnets.—Garnets suitable for abrasives, mostly almandite and grossularite, occur in the pre-Cambrian rocks of the Mica Mine locality, western Van Horn Mountains, on the Hudspeth-Culberson county line, in Trans-Pecos Texas, and of the Llano uplift of central Texas. Grossularite, produced by contact metamorphism of limestone intruded by granite and porphyry, is common in the Quitman Mountains of southern Hudspeth County.

Kyanite.—Kyanite has been observed by the writer in metamorphic calcareous rocks of the pre-Cambrian in northeastern Gillespie County, central Texas. Because this aluminum silicate, with the same composition as andalusite, sillimanite, and mullite, is greatly in demand as a high-grade refractory and for the manufacture of spark plugs and is even being made artificially, a more extensive search should be made for it. One of the important new uses for aluminum silicate ($Al_2O_3.SiO_2$) is for the production of nearly unbreakable chinaware.

Mica.—Mica in fairly large books and sheets is rather abundant in the pegmatites of the Mica Mine locality, western Van Horn Mountains, on the Hudspeth-Culberson county line. Smaller flakes have been utilized in so-called "micolithic" products, or facings for artificial stone. The larger sheets have been used for sheet mica and electrical appliances, while others have been used as a lubricant. Mica, also of pre-Cambrian age, is common in schists and pegmatites of the Llano uplift, central Texas.

Molybdenite.—Molybdenite is found in some of the pegmatite dikes of the Llano uplift, as on Honey Creek, about one-half mile west of Packsaddle Mountain, Llano County, and in small quantities in the Granite Mountain quarry, Burnet County. It also occurs with disseminated flake graphite in some marbles and calcareous schists, where care must be taken not to mistake it for the more abundant graphite. Molybdenite will make a mark on white paper which upon being rubbed becomes a greasy green. Molybdenum is used mainly in toughening steel and iron and in a hard substance for cutting steel and rock drills known as stellite, which is an alloy of cobalt, chromium, molybdenum, with or without tungsten.

Phosphates.—Rock phosphate in quantity sufficient to have commercial value is not known in Texas. Small amounts of phosphatic nodules occur in the Permian sandy shale of the headwaters basin of Cibolo Creek, Chinati Mountains, Presidio County, in the basal Midway Eocene and at the bases of some of the Upper Cretaceous formations in the eastern part of Texas. Some Ordovician limestones of the Marathon and Solitario areas of Trans-Pecos Texas have a phosphatic content but there is no definite information of the amount which exists in these rocks.

Tin minerals.—Tin oxides, cassiterite and stannite, are found in intrusive granite on the east flank of the Franklin Mountains, 12 miles north of El Paso. The entire production has had a value of about $5000. The tin minerals are associated with quartz veins occupying joint openings. The cassiterite is more abundant in the granite of the vein walls, where it is associated with quartz and feldspar, which are locally completely replaced by it, and with small amounts of wolframite, topaz, tourmaline, and fluorite. The deposit was probably made by eruptive or pneumatolytic after-effects subsequent to the consolidation, by cooling, of the granitic magma. Some stream or placer tin oxide has been found in Mason and Llano counties, more especially near Streeter and in Herman Creek, Mason County.

Vesuvianite.—Vesuvianite, used as a precious stone and as a substitute for jade, occurs in some of the pre-Cambrian marbles of Llano County. Another jade substitute is a very fine-grained mixture of epidote and a feldspar near anorthite, carrying also minute octohedral crystals of magnetite. The writer found the latter substitute near the barite workings on the Alfred Davis ranch in northeastern Gillespie County.

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MINERAL SALTS

The ordinary chemical analysis of water does not show the potassium and sodium contents as separate entities, and no determination of such substances as bromine, iodine, ammonium, barium, strontium, nitrates, and others are made in the ordinary analysis. At the writer's instructions the analyst determined the percentage of potassium which was found to be present in surprisingly large amounts in the waters of the Panuco oil field, Mexico. Incidentally there was also demonstrated the presence of considerable ammonium in these waters. Paul Weaver deduced from theoretical reasoning that the anhydrite of the Permian basin of west Texas should contain connate water, and it was discovered upon analysis that the edge or flank water in the Yates oil field of Pecos County has a mineral content ten times as high as that of the present ocean, consisting mainly of calcium and magnesium chlorides. The late Charles Paige of Sand Springs, Oklahoma, was forced by damage suits of land owners to dispose of saline waters yielded by his oil wells. In this way he was led to establish a chemical industry producing some twenty profitable chemical products. Instances are known of wildcat wells which failed to produce oil and yet found waters containing chemical substances which would yield a profit. In a considerable part of the Permian basin the underground waters contain a percentage of Glauber salts (sodium sulphate) sufficiently high to be profitably extracted. Drill cores from some of the southeast Texas salt dome oil fields possess a strong odor of either iodine or bromine. The Jones Chemical Company have plants at Shreveport, Louisiana, and Long Beach, California, where iodine is recovered from oil field brines. The brine associated with the oil in the Saratoga salt dome, Hardin County, Texas, contains considerable barium which is deposited as barium sulphate inside the screen and casing. The great salt deposits of the Permian basin are apt at least in some places to have either in solution in underground water or in beds associated with the salt, profitable quantities of bromine, iodine, calcium chloride, Glauber salts, or more than one of these. At least, salt beds elsewhere in the United States are yielding these substances. If complete analyses of the waters encountered in deep wells were made more generally, it is probable that Texas would become the headquarters for more chemical industries.

BROMINE AND CALCIUM CHLORIDE AND IODINE

Most of the bromine output is sold as potassium and sodium bromide, ethylene dibromide, and other bromine compounds. The value of bromine ranges from 20 cents per pound upwards, and the country's annual production is from 5,000,000 pounds to greater amounts. Calcium chloride from natural brines and mineral raw materials only (much is made in addition) varies from 50,000 tons upwards, and its value is $18 per ton upwards. Most of the iodine comes from Chile as a by-product from nitrates but is also being obtained directly from ocean water, from brown algae (kelp), and from two plants at Long Beach, California, and one at Shreveport, Louisiana, recovering it from oil-well waters. The value of crude iodine varies generally between $3 and $4 per pound. Ethylene dibromide is used in the manufacture of high-powered gasoline.

None of the products is being recovered in Texas at the present time.

SODIUM AND POTASSIUM NITRATE

Nitrates of sodium and potassium are very soluble in water and, therefore, never occur in large quantities at the surface except in an almost rainless country. Rainfall in any part of Texas is too great to permit the preservation of large deposits and, in fact, the small quantities which are known are in the drier Trans-Pecos section of the state in the Big Bend country of Presidio and Brewster counties. Valuable nitrate deposits, if they exist in Texas, will be found underground where they are effectually sealed off from water.

Most of the nitrates of west Texas are in rock shelters and caves, which have been dens for animals, including bats, and camps or more permanent homes of Indians. These deposits originate in excrements. Below, or west of the Rim Rock scarp in Presidio County, from the Capote ranch to Candelaria, some nitrate appears to be disseminated in the volcanic rock, both in the tuffs and in partly altered lavas. It is possible that such nitrate may prove profitable, because it is likely that it has originated from nitrous oxide vapors emitted by volcanoes. A third possible origin for nitrate is from fixation of the atmospheric nitrogen by the electrical disturbances during thunder storms. All these sources have been invoked to account for the sodium nitrate deposits of the almost rainless desert of northern Chile, the only commercial source of supply of natural nitrate. Much nitrate is now made synthetically directly from the atmospheric nitrogen in places where cheap electric power is available for generating the necessary high temperatures in the electric arc or furnace. Sulphate of ammonia is a by-product of coal and coke.

The most important use of nitrate is as fertilizer since nitrate, phosphorous, and potash are the three basically essential plant foods. Nitrate can be supplied to the soil by nitrogen-fixing bacteria which are associated with the roots of all the numerous leguminous plants. Consequently, crops of peas, beans, alfalfa, vetch, or clover will supply essential nitrogen to soils. Nitrates are used also in explosives and chemicals, nitric acid, sulphuric acid, glass, and dyes. The United States ordinarily uses about a million pounds yearly of Chilean nitrate.

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Additional references to the literature are contained in the first two references cited.

SODIUM SULPHATE (GLAUBER SALT)

Sodium sulphate, known as Glauber salt, occurs either as the minerals thenardite, banksite, glauberite, and mirabilite, or in solution in the waters of wells, or in lakes in dry regions. Thenardite is anhydrous, mirabilite contains 10 molecules of water, glauberite is a double sulphate of sodium and calcium, and banksite has the formula 9 $Na_2SO_4.2Na_2CO_3.KCl$. Glauberite is only slightly soluble in water; the others range from readily to very soluble compounds. All when pure occur as transparent, colorless crystals with salty to bitter tastes.

Glauber salt is used in dyeing, in tanning, as a mordant assistant in the textile industry, in medicine (especially veterinary remedies), in the preparation of cooling mixtures, and especially in paper and glass making. It is also known commercially as salt cake.

Supplies of Glauber salt are known in all the western mountain and desert states. Texas is the state farthest east and south in the United States in which Glauber salt deposits occur. The deeper or "alkali lakes" of the Llano Estacado and Pecos Valley contain sodium salts. In the northern and central Llano Estacado the lakes are salt-soda, that is, their waters contain mainly mixtures of common salt and sodium sulphate. The southern part of the Llano Estacado and the adjacent Pecos Valley have a number of more or less permanent lakes which contain relatively large percentages of sodium sulphate. Among these are two in Sulphur Draw a short distance west of Big Spring, Howard County, the soda lakes in Pecos Valley between Pecos City and Porterville (Mentone), and especially the one northeast of Royalty, Ward County, a mile east of the Monahans-Grand Falls road, 14 miles south of Monahans. In addition the gypsite variety of "caliche" underlying the sand hill area of Ward, Winkler, Crane, and Ector counties contains some sodium sulphate.

The lake near Royalty is now being exploited by the Ozark Chemical Company, which is pumping brine from numerous shallow wells beneath the lake and its surroundings. This is probably the only place in the country, and perhaps in the world, where Glauber salt is produced from underground water. During dry weather, probably all three common sodium sulphate minerals crystallize on the lake bottom (playa). Probably hydrous mirabilite is here precipitated and, when thoroughly dried, becomes anhydrous thenardite. The strongest brine occurs just below the playa surface with 37.16 per cent total solids, comprising 21.65 per cent Na_2SO_4, 10.26 per cent $CaSO_4$, and 5.49 per cent NaCl. Some of the deeper brines carry calcium sulphate and common salt in solution. The richest brine analyzed contained 27.8 per cent sodium sulphate.

It is suggested that the Glauber salt here is formed by double decomposition between common salt and some sulphate. The latter is more apt to be $MgSO_4$, according to the following reaction: $MgSO_4 + 2\ NaCl = Na_2SO_4 + MgCl_2$. The source of the brine is leakage from the saline residues of the underlying Permian, all waters in the Permian having hydrostatic head sufficient to reach within a few feet of the elevation of the playa surface. The same mode of origin and other conditions presumably apply to the other "alkali lakes."

Underground waters of the Trinity Cretaceous of central Texas, of the Pennsylvanian at Mineral Wells, and of the hot springs of Trans-Pecos Texas contain considerable quantities of sodium sulphate.

Much sodium sulphate is made as a by-product in the manufacture of hydrochloric (muriatic) acid and nitric acid from common salt. There is an unlimited quantity of raw materials, *i.e.*, salt and niter cake, the quantity of Glauber salt produced not being nearly enough to utilize all the cake. In connection with the potash industry of Germany, during the winter a large quantity of Glauber salt is made from a solution of magnesium sulphate (Epsom salts) and common salt, which chemicals at freezing temperature and below combine to form magnesium chloride and sodium sulphate.

The natural salt is produced, except in Texas, from brines in lakes or from the dried up deposits of former lakes. Because there is probability that much of the second-growth pine timber, as well as other forms of cellulose, such as cotton, rice, wheat, and corn stalks, in Texas and other states will be converted into paper (including white paper) there may be an important future for Texas Glauber salt, and more underground waters of the Permian basin should be analyzed for it.

Reference should be made to the "Report on Texas alkali lakes," by Meigs, Bassett, and Slaughter, University of Texas Bulletin 2234, 1922, for some of the "alkali lakes." The following percentage composition of dissolved substances, analysis made by the Bureau of Industrial Chemistry, University of Texas, from a sample of the surface lake brine of Cedar Lake, Gaines County, collected in the summer of 1932 by the writer, gives good indications of the composition of the underground waters beneath the lake. The total salinity of the lake water varies greatly with rainfall and temperature, although the percentage of the various ingredients is somewhat more constant.

Analysis of Water of Cedar Lake, Gaines County

	Per cent
Carbonates	0.034
Chloride	36.33
Sulphate	27.60
Magnesium	1.595
Calcium	0.3625
Sodium	32.33
Potassium	1.845
Total	99.996
Salinity percentage (total dissolved solids)	28.37
Percentage sodium chloride	58.5
Percentage sodium sulphate	28.83

The last two figures are theoretical and approximate only. The potassium and magnesium compounds and the common salt are to be considered as possible by-products. Solar evaporation and the abundant supply of natural gas are the evaporating agents likely to be used.

The production of the United States of natural sodium sulphate from lakes and former lake deposits has averaged about 32,500 tons annually for 1930, 1931, and 1932, which years show the greatest production yet recorded. During these years the average price has been about $6.30 per short ton.

THE TEXAS-NEW MEXICO POTASH DEPOSITS[1]

G. R. MANSFIELD[2] AND W. B. LANG[3]

NAME AND USES

The name "potash" is derived from "pot ashes," an impure mixture of potassium carbonate and other salts, formerly obtained by leaching wood ashes and evaporating the solution to dryness. As now used the name is applied to the theoretical oxide, K_2O, which is made the basis of all trade in salts containing potassium. Potassium oxide, however, is not found in nature or manufactured in commerce.

Potash through its many compounds is one of the soil ingredients necessary to plant life. It is naturally supplied to most soils by the slow decomposition of grains of feldspar and other minerals, but the extensive growth and harvesting of crops in agriculture removes potash from the soils more rapidly than it can be supplied by natural agencies and causes depletion, which must be remedied by artificial means if soil fertility is to be maintained. Potash is therefore a prime constituent of most fertilizers. Of all the potash-bearing materials imported into this country or manufactured here about 93 per cent, according to the Bureau of Mines, is used for this purpose. Small amounts of potash are also essential for certain chemical industries, such as tanning, dyeing, and electroplating. It is also used in metallurgy, photography, medicine, and miscellaneous chemical uses and in the manufacture of soap, glass, matches, and explosives.

CONSUMPTION IN THE UNITED STATES

As so large a part of imported or domestically produced potash is consumed in fertilizers and as fertilizers are sold chiefly to farmers, the consumption of potash is closely linked with the general agricultural conditions of the country and rises and falls as agriculture is more or less prosperous. For example, "in the United States, farm income shrank from $11,900,000,000 in 1929 to $5,240,000,000 in 1932; fertilizer sales dropped from the 1930

[1]Published by permission of the Director, U. S. Geological Survey.
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[3]Geologist, U. S. Geological Survey.

peak of 8,200.000 tons to 4,250,000 tons in 1932; and potash consumption [in terms of K_2O] declined from 390,000 short tons in 1930 to 167,665 in 1932."[4] In 1933, with improved conditions for the farmer, both the domestic production and the importation of potash salts showed marked increases, as shown in tables beyond. The total consumption in 1933 was 293,000 short tons of K_2O, contained in 775,549 tons of crude salts, valued at $15.909,724.

Of the potash used in agriculture 93 per cent[5] is consumed east of the Mississippi River, largely in the Atlantic and eastern Gulf States and those adjacent to the Great Lakes. The remainder is consumed west of the Mississippi—5 to 6 per cent in States along the west bank of that river and in Texas, about 1 per cent in the Pacific Coast States, and less than half of 1 per cent in the Great Plains and Rocky Mountain States.

Estimated annual consumption of potash (K_2O) in 1929,[6] by States
(Short tons of K_2O)

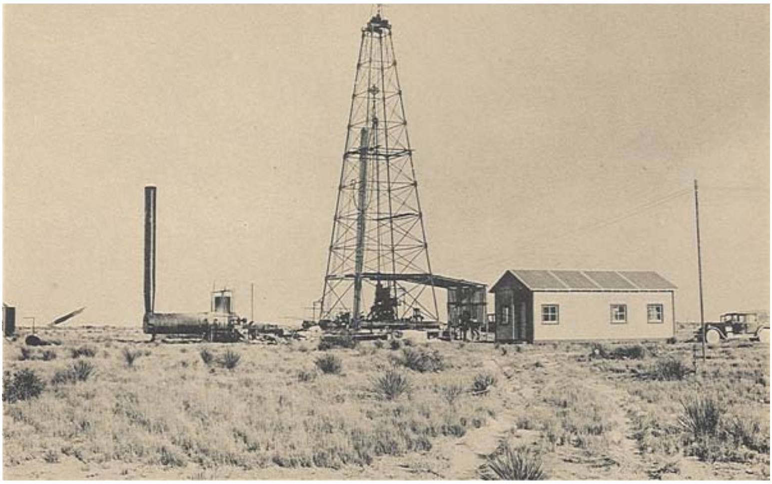
1. North Carolina	44,000	25. Delaware	2,340
2. Georgia	32,400	26. Wisconsin	2,270
3. South Carolina	28,700	27. Missouri	1,180
4. Florida	27,000	28. West Virginia	900
5. Alabama	25,000	29. New Hampshire	850
6. Pennsylvania	23,000	30. Vermont	750
7. Indiana	18,361	31. Minnesota	747
8. Ohio	13,540	32. Rhode Island	500
9. New York	13,250	33. Washington	350
10. Maine	12,860	34. Iowa	340
11. Virginia	11,825	35. Oklahoma	280
12. Mississippi	11,000	36. Oregon	200
13. Maryland	7,779	37. Kansas	150
14. New Jersey	7,600	38. North Dakota	10
15. Texas	5,975	39. Nebraska	10
16. Arkansas	5,460	40. Colorado	10
17. Michigan	4,960	41. Arizona	10
18. Louisiana	4,800	42. New Mexico	10
19. Tennessee	3,575	43. South Dakota	5
20. Connecticut	3,450	44. Montana	
21. Massachusetts	3,213	45. Wyoming	
22. Kentucky	2,790	46. Idaho	
23. California	2,600	47. Utah	
24. Illinois	2,394	48. Nevada	

A large proportion of the potassium salts consumed in the United States as plant food is applied to cotton, potatoes, and tobacco. Large quantities are also used for truck crops.

[4]Hedges, J. H., Potash: U. S. Bur. Mines, Minerals Yearbook, 1932–33, p. 763, 1933; *idem*, 1934, pp. 1031-1046, 1934.

[5]Johnson, B. L., Potash: U. S. Bur. Mines, Econ. Paper 16, p. 46, 1933.

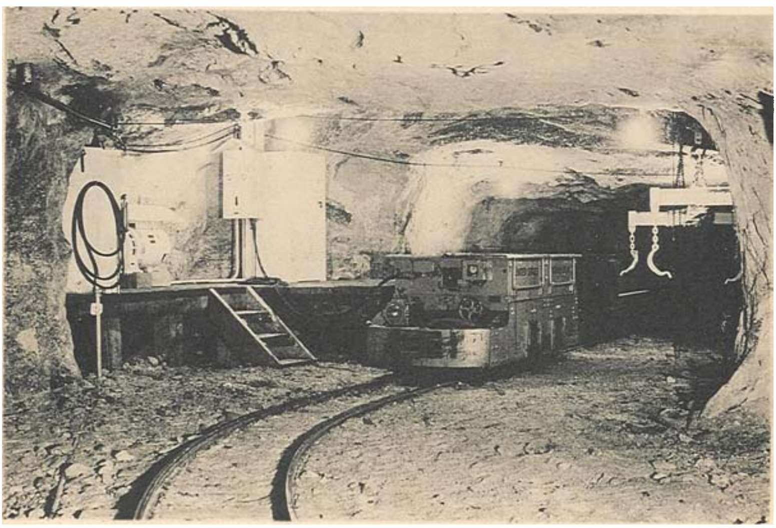
[6]Smalley, H. R., cited by Johnson, B. L., *op. cit.*



A. United States Potash Co.'s mine, Eddy County, New Mexico. View to southeast, showing power house, head frame, mill house, and loading bin. September, 1932.

B. Prospecting for potash. Second Government potash core test (New Mexico No. 2), Eddy County, New Mexico. May, 1927. Photographs by W. B. Lang.

A. Heading in the United States Potash Co.'s mine, Eddy County, New Mexico. Showing the banded halite-sylvite ore. In the foreground is ore freshly shot from the heading.



B. Battery-charging room cut in sylvite ore in the United States Potash Co.'s mine. Photographs by W. B. Lang.

DOMESTIC PRODUCTION AND SALES OF POTASH

According to the Bureau of Mines,[7] potash produced in the United States in 1933 amounted to 333,110 short tons of potassium salts, equivalent to 143,378 short tons of potash (K_2O)—an increase of 133 per cent in gross weight and of 131 per cent in K_2O content over 1932 (143,120 tons potash salts; 61,990 tons K_2O).

The sales of 325,481 tons of potash salts with a potash content of 139,067 tons in 1933 were 2 per cent and 3 per cent respectively less than the production but 168 per cent and 150 per cent respectively more than in 1932 (121,390 tons potash salts; 55,620 tons K_2O). The value of the potash salts sold was $5,296,793, an increase of 152 per cent over 1932 ($2,102,590). The average value per ton was $16.27 in 1933, compared with $17.32 in 1932. The value per unit (20 pounds) of K_2O was 38.1 cents, compared with 37.8 cents in 1932. Stocks of potassium salts at the end of 1933 were 46,943 short tons, with an available content of 20,891 tons of K_2O.

Increased output of crude and refined salts at Carlsbad, New Mexico, accounted for much of the large increase in production and marked the second full year of shipments from this locality. The other sources of potash salts in 1933 were salines from Searles Lake at Trona, California; molasses distillery waste at Baltimore, Maryland; and dust from cement kilns near Hagerstown, Maryland. Small quantities of alunite were shipped from Marysvale, Utah, chiefly for experimental use as fertilizer material. The available K_2O content of the salts sold in 1933 ranged from 23 to 62.5 per cent.

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[7]U. S. Bur. Mines Minerals Market Rept. M.M.S. 274, Potash industry in 1933, advance final summary, April 20, 1934; Minerals Yearbook, 1934, pp. 1031-1046, 1934.

Potassium salts produced, sold, and in stock in the United States, 1928–33[1]

Year	Production			Sales				Stocks		
	Number of plants	Potassium salts (short tons)	Equivalent as potash (K_2O) (short tons)	Number of plants	Potassium salts (short tons)	Equivalent as potash (K_2O) (short tons)	Value f.o.b. plant	Number of plants	Potassium salts (short tons)	Equivalent as potash (K_2O) (short tons)
1928	9	104,129	59,910	5	105,208	60,370	$3,029,422	7	6,260	2,100
1929	5	107,820	61,590	4	101,370	57,540	2,988,448	5	12,650	6,200
1930	5	105,810	61,270	4	98,280	56,610	2,986,157	5	20,550	11,000
1931	6	133,920	63,880	6	133,430	63,770	3,036,955	3	20,000	10,500
1932	5	143,120	61,990	5	121,390	55,620	2,102,590	3	41,000	28,000
1933	5	333,110	143,378	4	325,481	139,067	5,296,793	4	46,943	20,891

[1]Hodges, J. H., *op. cit.*, p. 767. U. S. Bur. Mines Minerals Yearbook 1934, p. 1036, 1934.

IMPORTS

In 1930,[3] when the annual consumption of potash in the United States was at its maximum, 85 per cent of the amount consumed was of foreign origin, coming originally almost entirely from

[3]Johnson, B. L., *op. cit.*

Germany and France, with a little from Spain. In 1933 American producers supplied 41.3 per cent of the domestic requirements and 58.7 per cent was imported. Germany and France continued to be the main sources of imported supplies but Spain, Palestine, and the Soviet Union also contributed to the total.

Detailed figures for imports of potash-bearing salts, specifying types of salts and countries of origin, are published each year by the Bureau of Mines.[9] For present purposes it is not necessary to go into these figures in detail. However, in order to show the general magnitude of the potash trade in the United States it is desirable to cite summary figures for the last few years. These are given in the following table:

Potash materials imported for consumption in the United States, 1928–33[a]

Year	Use	Quantity (short tons)	Approximate equivalent as potash (K_2O) Short tons	Per cent of total	Value
1928	Fertilizer	931,616	310,000	93.8	$18,227,830
	Chemical industries	44,045	20,493	6.2	4,292,162
		975,661	330,493	100.0	22,519,992
1929	Fertilizer	870,502	297,000	91.5	17,629,535
	Chemical industries	58,968	27,638	8.5	6,043,106
		929,470	324,638	100.0	23,672,641
1930	Fertilizer	933,324	322,000	94.1	19,905,069
	Chemical industries	45,682	20,084	5.9	4,589,457
		979,006	342,084	100.0	24,494,526
1931	Fertilizer	528,764	194,100	90.4	12,225,733
	Chemical industries	48,431	20,685	9.6	4,274,749
		577,195	214,785	100.0	16,500,482
1932	Fertilizer	287,929	96,170	84.7	5.711,347
	Chemical industries	43,035	17,337	15.3	3,130,491
		330,964	113,505	100.0	8,841,838
1933	Fertilizer	425,571	149,090	86.8	8,351,428
	Chemical industries	53,858	22,764	13.2	3,465,030
		479,429	171,854	100.0	11.816,458

[a]Compiled from Mineral Resources and Minerals Yearbook, U. S. Bur. Mines

[9]Minerals Yearbook, formerly Mineral Resources of the United States.

EXPORTS

Some potassium salts are exported from the United States, but the quantity is relatively small. Since 1929 the Bureau of Foreign and Domestic Commerce has published data on exports of potassium-bearing fertilizer materials separately from those of other fertilizer materials. The following table shows exports of potash-bearing materials used for fertilizer and for other purposes. The potassium content of the exported material is not known, but on account of the large amount of muriate the content is estimated as averaging 45 to 60 per cent. More than 80 per cent of the shipments go from Pacific Coast customs ports. Japan is the largest customer, but shipments are also made to several other countries.[10]

Exports of potash material from the United States, 1929–32[a]

Year	Use	Quantity (short tons)	Value
1929	Not fertilizer	1,523	$ 583,668
	Fertilizer	15,532	582,690
		17,055	1,166,358
1930	Not fertilizer	1,256	498,774
	Fertilizer	17,042	643,367
		18,298	1,142,141
1931	Not fertilizer	1,158	370,935
	Fertilizer	32,460	1,267,109
		33,618	1,638,044
1932	Not fertilizer	887	241,179
	Fertilizer	2,034	70,028
		2,921	311,207
1933	Not fertilizer	1,275	301,596
	Fertilizer	28,086	901,931
		29,361	1,203,527

[a]Coons, A. T., *op. cit.;* Hedges, J. H., *op. cit.*, p. 772.

FOREIGN SOURCES OF SUPPLY

Potash-bearing materials are imported into the United States from several countries, but the apparent country of origin is not invariably the original source of the potash, which has been and

[10]Coons, A. T., Potash in 1931: U. S. Bur. Mines Mineral Resources of the United States, 1931, pt. 2, p. 29, 1932; *idem*, 1930, pt. 2, p. 64, 1931.

still is largely the German and French group of deposits that has so long served as the basis of the monopolistic control of the potash industry by these two countries. There are, however, deposits of considerable size and commercial importance in other countries, and some of these are being operated on a scale sufficient to assure them a place in the world's potash markets, though their reserves are not yet very well known. Such figures as are available, however, show that these deposits are undoubtedly large and, together with the German and French deposits, capable of supplying the potash needs of the world for centuries to come. The principal deposits of this group are those of Poland, the Soviet Union, and Spain. In addition, the waters of the Dead Sea are being treated for the recovery of potash salts by a British company with British and American capital.[11]

Germany.—The potash deposits of Germany occur in the Zechstein (Permian) beds, which were formerly continuous over most of Holland, Germany, and Poland and extended into Russia. By subsequent structural disturbances and erosion the Zechstein beds have become folded, faulted, and more or less discontinuous, so that the potash beds are now found in more or less distinct areas or districts, such as Stassfurt, Hannover, South Harz, and Werra-Fulda. The potash-bearing beds are mostly inclined at different angles and range in depth from 650 to 5000 feet in some of the synclines. Two salt-bearing series have been recognized, but, except in the Hannover district,[12] potash salts have been found only in the lower series. Beds containing sylvite are reported to range at some localities from 2 to 25 feet in thickness; zones of carnallite reach 140 feet, and of polyhalite 300 feet. The thicker zones are composed of low-grade material. The principal economically important salts are sylvite, kainite, and carnallite. Other potash-bearing salts present are chiefly of scientific interest. Estimates of the productive area are as high as 24,000 square miles and of reserves of potash (basis, 12½ per cent of K_2O) from 2,500,000,000 to 438,000,000,000 metric tons of K_2O, of which 86 per cent is said to lie within 4000 feet of the surface.

As a consequence of overexpansion the German industry since 1910 has been under state control, so designed as to conserve

[11]Johnson, B. L., *op. cit.*, p. 73.
[12]Johnson, B. L., *op. cit.*, pp. 48-57.

invested capital and profits and to regulate prices without jeopardizing markets. The result as a whole has been favorable, although the farmers of the world have been taxed to make good the unwise investments of the earlier potash producers. Turrentine[13] says:

> The advantages possessed by the German-French cartel, represented by excellent deposits, experienced staffs, economical chemical processes yielding valuable by-products, cheap water transportation virtually from the mine to the foreign port of entry, constructive world-wide propaganda, and, above all, sympathetic governmental solicitude, represent a combination of favorable circumstances, natural and designed, not easily matched.

France.—The French (Alsatian) deposits are in the upper Rhine Valley immediately north of Mulhouse, in Oligocene (Tertiary) sediments near the south end of the Rhine graben and possibly extending across the Rhine to Buggingen, Baden. The area containing the deposits as outlined by drilling is about 70 square miles. The beds have generally gentle dips but are locally folded and faulted. Two beds separated by a 50- to 70-foot interval and at depths ranging from 1625 to 2850 feet contain the potash-bearing salts. The lower, thicker bed, from 6 to 18 feet thick, extends throughout the area and ranges from 23 to 32 per cent KCl, equivalent to 15 to 21 per cent K_2O. The upper bed, 2 to 6 feet thick, covers only 33 square miles but is richer (20 to 25 per cent K_2O). The deposit consists almost entirely of mixtures of sodium and potassium chlorides. Estimates of reserves range from 300,000,000 to 323,400,000 metric tons of K_2O. Mining has thus far been limited chiefly to the lower bed.[14] Since the World War the French deposits have been largely Government-owned, and their output has been sold through the German-French cartel above mentioned.

Spain.—The Spanish potash deposits are in northeastern Spain,[15] in the Ebro Basin, in Tertiary (Oligocene) sediments, which have been folded into long anticlines. The deposits have been developed at Suria, Cardona, and Sallent, in the province of Catalonia, but drilling has been done at numerous other places. The potassium minerals are chiefly carnallite and sylvite, the former the more

[13]Turrentine, J. W., Potash as an international commodity in 1932: Amer Fertilizer, vol. 79, no. 10, pp. 14–15, Nov. 4, 1933.

[14]Johnson, B. L., *op. cit.*, pp. 57–62.

[15]Johnson, B. L., *op. cit.*, pp. 62–65. Dawson, C. I. (consul general, Barcelona), Spanish potash in 1933: Bur. Foreign and Domestic Commerce, Spec. Circ. 382, Chem. Div.

abundant. The area considered exploitable contains about 248 square kilometers, and the reserves for Suria and Cardona are estimated at about 272,000,000 metric tons of equivalent K_2O. Potassium salts of commercial grade occupy two distinct zones —a lower one, 7 to 26 feet thick, present only in certain localities at the base of a bed of rock salt 1000 feet thick, and an upper one, about 200 feet thick, at the top of this salt body. The upper zone is the only one worked. Sylvite beds as much as 25 feet thick occur at the base of this zone, but carnallite predominates in the rest of the zone. The workable sylvite salts contain potassium equivalent to 18 to 34 per cent K_2O, whereas the crude carnallite averages 12 per cent. The deposits belong to the Spanish State and can be exploited only under Government concessions and under specified conditions.

Three companies were operating in 1933, but 63 others have been active at different times. Of these Potasas Ibéricas, organized in 1929 and French-controlled, is working a deposit near Sallent and is the principal shipper to the United States. It does not yet have a refinery, but the exceptionally high grade of its deposits enables the company to deliver salts ranging from 15 to 50 per cent K_2O without other treatment than sorting and crushing.

Exports of Spanish potash to the United States during the past last few years have shown a marked rate of increase:

Potash salts exported from Spain to the United States, 1928–33, in metric tons

1928	9,930	1931	22,438
1929	21,591	1932	10,635
1930	18,372	1933	51,855

Poland.—Potassium salts occur in two well-defined areas in Poland. One is the eastern extension of the Zechstein (Permian) beds of Germany. This is in northwestern Poland, and little is known of the extent and character of the potash deposits it contains, though borings have disclosed considerable thicknesses of carnallite-bearing salts at different depths and places. The other is in southeastern Poland, in the northeastern flanks of the Carpathian Mountains, and contains the Kalusz, Holyn, and Stebnik areas, which are now being exploited. The potassium salts occur as large lenses interbedded in gray Miocene loamy strata. They range from 165 to 1650 feet in length and from 4 to about 400 feet in thickness.

They dip from 25° to 50° and range from 80 to 1000 feet in depth. The potassium salts of commercial interest are sylvite, kainite, and langbeinite, but carnallite and polyhalite are also present. The K_2O equivalent of the salts mined runs from 10 to 30 per cent and averages about 16 per cent. Official estimates of reserves for the Miocene deposits in 1928 were 100,000,000 metric tons of crude sylvite and kainite, equivalent to 10,000,000 to 12,000,000 tons of K_2O.

Production in recent years has been carried on by a single company, the "Tesp" (Society for the Exploitation of Potassium Salts), which operates under Government auspices. On March 17, 1932, an agreement was concluded between the German potash syndicate and the Polish Tesp whereby the Polish producers will have a 4 per cent quota in the world market now dominated by Franco-German interests. The German syndicate will control Polish potash production but will relinquish competition in the Polish market. Little potash from Poland has thus far reached the United States.[16]

According to private advices[17] considerable langbeinite is now being mined in Poland.

Union of Soviet Socialist Republics.—The deposits of potassium salts of present economic importance in the Soviet Union (Russia) are those of the Solikamsk-Bereznikov district, at about 60° north latitude, near the upper Kama River, about 125 miles north of Perm and 150 miles west of the Ural Mountains. Like the German deposits, they are of Zechstein (Permian) age. The beds have been little disturbed and are nearly horizontal. The potash-bearing salts do not crop out but have been revealed at depths of 250 to 800 feet by borings. The possibly productive area extending between Solikamsk and Bereznikov is about 25 miles long and 6 miles wide and thus includes about 150 square miles, but its limits are not known. There are two sylvite zones separated by a carnallite zone, and the whole is underlain by 800 to 1300 feet of rock salt. The upper sylvite zone, not present everywhere, has a maximum thickness of 65 feet. The carnallite zone is 200 to 300 feet thick, with reported workable beds totaling 115 feet and averaging 20 per cent KCl. The lower sylvite zone, 100 feet thick, is reported to contain 25 to 50 feet of workable beds, averaging 24.5 per cent KCl. No other

[16]Johnson, B. L., *op. cit.*, pp. 66-70. Hedges, J. H., *op. cit.*, p. 775.
[17]Smith, H. I., personal communication.

economically important potassium salts have been recognized. Reserves for the whole area of 150 square miles have been estimated by the Geological Committee of the Soviet Union to contain 4,000,-000,000 metric tons of crude salts, equivalent to about 700,000,000 tons of K_2O. Transportation facilities by both rail and water are available.[18]

Production at the mine at Solikamsk in 1933 was at the rate of 2000 to 2200 tons a day, the record for December being 48.500 tons. The mine has complete mechanical equipment and special facilities for a large corps of workers, including underground work shops and plant buildings, as well as surface facilities in which the social conditions of the workers are cared for. A similar mine is under construction at Berezniki (Bereznikov), 30 kilometers distant.[19]

In the spring of 1934 Russian potash appeared actively on the American market at prices considerably below those of the Franco-German salts. With the enormous supplies available and the large-scale mining developments now existing in the Soviet Union, it is to be expected that Russian potash will be an increasing factor in both American and world potash markets.

Palestine.[20]—The waters of the Dead Sea, which lies across the boundary of Palestine and Trans-Jordan, countries under British mandate, are estimated to contain 43,000,000,000 metric tons of dissolved salts, including magnesium chloride (22,000,000,000), sodium chloride (11,900,000,000), calcium chloride (6,000,-000.000), potassium chloride (2,000,000,000), and magnesium bromide (980,000,000). On January 1, 1930, Palestine Potash, Ltd., a British company with British and American capital, received a concession granting it exclusive right to extract potash and other mineral salts from the Dead Sea for 75 years.[21] This concern began production in 1930, using a solar evaporation process. In 1932 it produced 19,800 metric tons of potash salts containing 3960 tons (20 per cent) of K_2O. Production figures for

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[18]Johnson, B. L., *op. cit.*, pp. 70–71.

[19]Soviet potash for the collective and State farms: Pravda, Jan. 12, 1934; cited by Bur. Foreign and Domestic Commerce, March 15, 1934.

[20]Johnson, B. L., *op. cit.*, pp. 72–73. Hedges, J. H., *op. cit.*, p. 775; U. S. Bur. Mines, Minerals Yearbook, 1934, pp. 1045–1046. 1934.

[21]The validity of this concession is contested by a group of capitalists reported to be mainly French.

1933 are not yet available, but 3040 short tons of muriate were imported from Palestine into the United States, as compared with 500 short tons in 1932. The company reported that its entire output of potash and bromine was disposed of without difficulty.

PRICES

Except for the interval covered by the World War prices of imported potash salts on the American market have long been controlled by the German potash syndicate. They are quoted both for material in bulk and for material in bags and have ranged in recent years from about $8 to $48 a ton, according to grade and composition, kainite (12.4 per cent K_2O) in bulk representing the lowest figure and potassium sulphate (90 to 95 per cent K_2SO_4) in bags the highest. Muriate (80 to 85 per cent KCl) has sold for around $35 to $37, and prices of lower grades have been correspondingly less. Discounts are allowed under specified conditions, depending on quantities purchased, dates of orders, and other conditions. American production has met this competition without the protection of a tariff, potash and other materials used in the manufacture of fertilizers having been retained on the free list. In view of the high costs of labor and transportation in this country, as compared with European countries, it is a tribute to our potash producers that they have been able to do this. However, the recent introduction of lower-priced Russian and Spanish potash and the advent of Dead Sea potash on the American market add to the problems of the domestic producers, and foreign dumping may endanger the life of the domestic industry.

CONTROL

The potassium salts marketed in America from German, French, and some Spanish sources are handled by the N. V. Potash Export Mij., Inc., of Amsterdam, Holland, agents for the German and French syndicates. The Ibéricas (Spanish), Russian, and Dead Sea material, being independently offered, will no doubt have an effect on syndicate prices, though this has not been felt to any degree as yet. The two largest American concerns are in part at least foreign controlled. The United States Potash Co. is 50 per cent owned and operated by a British company. The American Potash & Chemical Corporation is managed by a British company, but the nationality of the controlling interest in it has not been disclosed.

THE SEARCH FOR POTASH IN THE UNITED STATES

The story of American potash has been told so frequently that little repetition of it need be given here. In 1910, when the German Reichstag passed a law establishing Government control of the German potash industry and thus invalidating contracts held by American consumers, the United States Government was stimulated to undertake a systematic search for sources of commercial potash in this country.

Congressional appropriations to the Geological Survey and Bureau of Soils began in 1911, and many possible sources were investigated, the Survey attempting to find natural sources of soluble potassium salts and the Bureau of Soils devoting attention to industrial processes and organic sources. During the war period private companies, using the various suggested sources, built up a considerable potash industry, represented by 128 plants and an investment of $50,000,000. Most of these plants, however, were based on high-priced potash and went out of business when lower prices returned. The two principal survivors are the American Potash & Chemical Corporation, processing brines from Searles Lake, California, and the United States Industrial Chemical Co., of Baltimore, Maryland, which recovers potash as a by-product of the manufacture of alcohol from molasses.

POTASH IN THE PERMIAN BASIN

Early discoveries.—Although the possibility of the presence of buried soluble salts of potassium in the Permian basin had long been recognized by geologists and cognizance of this possibility had been taken by the Geological Survey in its first chapter on potash (in Mineral Resources for 1910, published 1911), the credit for the first actual discovery belongs to Dr. J. A. Udden, late Director of the Texas Bureau of Economic Geology. In 1912 Udden found 5.4 per cent of potassium, calculated as chloride, in brine taken from a depth of 2200 feet in the Spur well, in Dickens County, Texas. The brine had been standing undisturbed in the well for 2 months. He later found 9.2 per cent of potash (K_2O) in some crystals of red salt taken between depths of 875 and 925 feet in a well drilled at Boden, in Potter County, in 1915. Similarly some red salt from depths between 1500 and 1700 feet in the Miller well, in Randall County, in the same year yielded 6.1 per cent of K_2O, and some colorless salt particles from a deeper portion of the same well assayed 10.5 per cent of K_2O.[22]

On the basis of these findings the Geological Survey in November, 1915, began a deep test boring for potash at Cliffside, in Potter County, 6 miles northwest of Amarillo. This was interrupted in March, 1916, by lack of funds but was later continued to a depth of 1703 feet and abandoned October 12, 1917. Though the chosen site of this well was between two wells that had previously furnished indications of the presence of potash, it disclosed no significant amounts of potash in the 400 feet of salt beds penetrated.

State and Federal coöperation.—The period 1918 to 1921 was marked by coöperative effort of the Texas Bureau of Economic Geology and the United States Geological Survey to obtain and study cuttings from wildcat oil wells that were then being drilled in the Texas Panhandle, the Llano Estacado, and farther south. In 1920 and 1921 these efforts were rewarded through the discovery by members of the coöperating bureaus of potash in cuttings from several deep tests—the Bryant well, in Midland County; the River well, in Ward County; the Burns well, in Dawson County; the Means well, in Loving County; the Long (G. A. Jones) well, in Borden County; and the McDowell well, in Glasscock County. The potash was in the form of the mineral polyhalite, which was first recognized by R. K. Bailey in the laboratory of the Geological Survey on February 17, 1921, in cuttings from the Bryant well submitted by D. D. Christner, of the Texas Bureau. In September, 1921, the Texas Bureau was forced by lack of funds to withdraw from the investigation.

Geological Survey.—From 1921 to 1932 the Geological Survey continued to maintain a representative in that part of the Permian basin previously discussed, which had come to be called the "Texas-New Mexico potash area." With the rapid increase in oil-drilling activity and the recurrent discoveries of polyhalite in the cuttings from these wells, it became evident that potash deposits were

[22]Udden, J. A., The deep boring at Spur: Univ. Texas Bull. 363, 90 pp., 1914; Potash in the Texas Permian: Univ. Texas Bull. 17, 59 pp., 1915; On the discovery of potash in west Texas: Chem. and Met. Eng., vol. 25, pp. 1179–1180, 1921.

widespread. The need for core drilling was recognized as more and more urgent and was constantly reiterated by the Geological Survey in its press notices and in the independent publications of its members. Moreover, though polyhalite was considered a very important resource in time of need, it was realized that for immediate recovery and industrial use it would be necessary to find deposits of the more soluble potash mineral sylvite, which forms the basis of most of the European trade in potash. The search for sylvite was redoubled. The oil companies and the public generally became more and more "potash-conscious." By the beginning of 1924 public sentiment in favor of Government core drilling had increased to the point where legislation for this purpose was demanded. In January of that year Senator Sheppard and Representative Hudspeth, both of Texas, presented bills in Congress calling for a 5-year program of Federal exploration for potash. These bills made only slow progress.

Meanwhile three important discoveries of sylvite were made. The first was in cuttings from a depth of 4300 feet in the Rycade Oil Corporation No. 1 Gray well, drilled in the Markham salt dome, in Matagorda County, Texas.[23] The presence of sylvite in these cuttings had been suspected by others, but it was first identified by R. K. Bailey in the Geological Survey laboratory on January 6, 1925. Although the age of the salt containing the sylvite and the time and mode of origin of the salt dome are still in doubt, the suggestion has been made that the salt is of Permian age, intruded into later sediments.[24] If this should prove true the salts would presumably have been deposited in a different and separate basin, now completely buried.

The second discovery, reported by R. K. Bailey on May 4, 1925, was made in connection with carnallite found in cuttings from the Crescent-Eagle well, Grand County, Utah.

The third discovery was made in cuttings from the McNutt No. 1 well, drilled by the Snowden & McSweeney Co. in sec. 4, T. 21 S., R. 30 E., about 25 miles northeast of Carlsbad, New Mexico. The sylvite was identified by R. K. Bailey in the Geological Survey

[23] DeGolyer, E. L., Discovery of potash salts and fossil algae in Texas salt dome: Amer. Assoc. Petr. Geol. Bull., vol. 9, pp. 348-348, 1925.

[24] DeGolyer, E. L., and others, Geology of Salt Dome Oil Fields, pp. 12-218, Amer. Assoc. Petr. Geol., 1926.

laboratory on November 19, 1925. This discovery heightened interest in the search for potash, especially among private companies, and encouraged Government action.

CORE-DRILLING CAMPAIGNS

FEDERAL

The Sheppard and Hudspeth bills finally took form in the potash act (44 Stat. 768) approved June 25, 1926, which provided $100,000 annually for a period of 5 years for joint explorations by the Geological Survey and the Bureau of Mines but contained such restrictions relative to the selection of drilling sites and to contracts with landowners or lessees that it proved practically unworkable and was later amended (44 Stat. 1388, approved March 3, 1927). Under this authorization the Geological Survey was to select the drilling sites and to receive, study, and report on the cores obtained; the Bureau of Mines was to make the necessary contracts with landowners, lessees, and drilling contractors and to conduct the drilling operations.

In all, 23 core tests were made in the Permian basin and one in Grand County, Utah. Of the 23 tests, 10 were in Texas and 13 in New Mexico. Their location is shown in Figure 32. Seventeen of the tests revealed more than 50 intersections of polyhalite beds that may be considered as having possible economic interest. These beds range in thickness from 2 to about 14 feet and in potash content from 10 to nearly 15 per cent. Commercial interest in many of these polyhalite beds is no doubt remote. Nevertheless, it should be borne in mind that the viewpoint of the Government toward mineral resources is somewhat different from that of industry. Industry seeks an immediate or early return upon invested capital, but the Government must foresee and provide for emergencies and for future requirements in mineral raw materials.

Twelve of the tests revealed the presence of sylvite, carnallite, or langbeinite. The 23d test disclosed an 11-foot bed of sylvite and halite, 5 feet of which contains more than 30 per cent of K_2O. This bed compares favorably in content and thickness with the salts now being mined in Eddy County, New Mexico. Three other tests, the 13th, 17th, and 22d, penetrated beds of similar salts

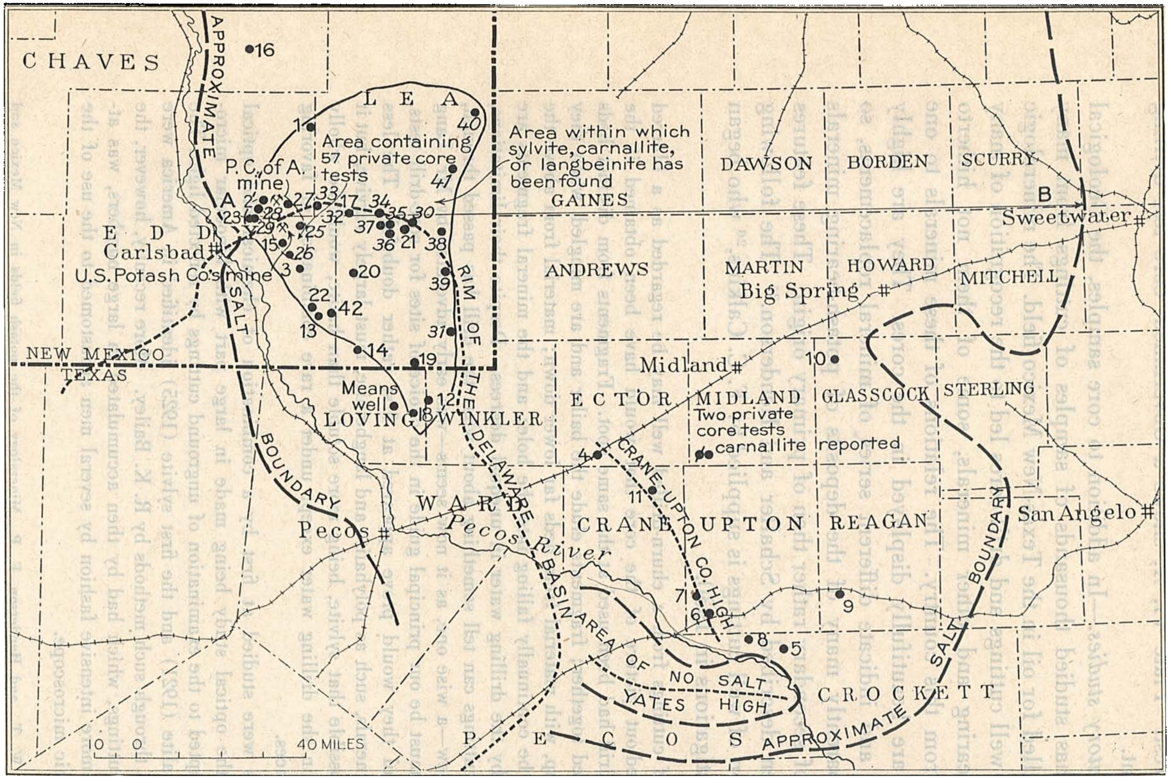

Fig. 32. Map of the southern portion of the Permian basin of New Mexico and Texas, showing the salt boundary, the area in which sylvite, carnallite, and langbeinite have been found, and the area of present economic interest for sylvite. The potash-bearing wells shown on this map are as follows: Nos. 1–23, Government core tests; Nos. 25–42, churn-drilled wells that have yielded sylvite, carnallite, or langbeinite. The churn-drilled wells are as follows: 25. S. & M. McNutt No. 1; 26. Ohio-Workman No. 1; 27. Marland-Hale No. 1; 28. Getty-Nicholas No. 1; 29. S. & M. Lawrence No. 1; 30. Empire-State 1-C; 31. Gypsy-Humphreys No. 1; 32. Empire-Martin No. 1; 33. Texas-Humphreys No. 1; 34. Texas-Lynch No. 1; 35. Snowden McSweeney-State No. 1; 36. Amerada-State No. 1; 37. Cranfill & Reynolds State 1-D; 38. Continental-A. E. Meyer No. 1; 39. Continental-Wm. Meyer No. 1; 40. Barnsdall-Bronson No. 1; 41. National Securities-T. A. Linam No. 1; 42. Marland-Gardner No. 1.

but of lower grade that may also be considered of possible commercial interest. Plate VI, *A*, shows a Government core test drilling equipment.

Laboratory studies.—In addition to core samples, the Geological Survey has studied thousands of samples of cuttings from many wells drilled for oil in the Texas-New Mexico field. The mineralogic study of well cuttings and drill cores led to the recognition of many potash-bearing and other minerals, some of them not hitherto known from this country. The relations of these minerals to one another are beautifully displayed in the cores. They are highly complex and indicate different series of mineral replacements, so that apparently many of the deposits of potash-bearing minerals may be of secondary rather than of primary origin. These features have been described by Schaller and Henderson.[25] The following discussion of well cuttings is supplied by F. C. Calkins,[26] who began his investigations in 1930.

A set of cuttings from a churn-drilled well may be regarded as a blurred and washed-out picture of the core that would have been obtained if the diamond drill had been used at the same spot. Fragments from distinct beds are jumbled together; fragments elude the bailer and are mingled, when they do come up, with material from beds far lower down; material from above the drill may be continually falling into the hole; and the mineral fragments are dissolved by the drilling water in unequal degrees. Despite their limitations. however, cuttings can tell something about what the drill has passed through, and the view—a wise one, as it now seems—was early advocated by Mr. Lang that they must be our principal guide in the choice of sites for core-drill tests. How useful they would prove appeared at first rather doubtful. The less soluble minerals, such as polyhalite and langbeinite, must largely survive, but it seemed possible that sylvite, being more soluble than halite, would be wholly dissolved in the drilling water except under a rare combination of favoring circumstances.

Cuttings were studied at first by a combination of chemical and optical methods, the optical study being made in large part with binocular microscopes adapted to the examination of unground cuttings by reflected light. The first polyhalite (1921) and the first sylvite (1925) identified in America were discovered through such methods by R. K. Bailey. More recently, however, the study of cuttings, which had by then accumulated in large numbers, was attacked in more intensive fashion by several men accustomed to the use of the petrographic microscope.

[25]Schaller, W. T., and Henderson, E. P., Mineralogy of the potash fields in New Mexico and Texas (abst.): Mining and Metallurgy, vol. 10, pp. 197–198, April, 1929; Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Geol. Surv., Bull. 833, 124 pp., 1932.

[26]Calkins, F. C., unpublished manuscript.

The opinion was soon reached independently by two or three of these workers that the most complete and reliable knowledge of the composition of the cuttings could be obtained by examining them in finely powdered form with the petrographic microscope, using what is well known to petrographers as the *immersion method*. The minerals are identified mainly by comparing their refractive indices with oils of known refractive index in which they are immersed. A few modifications, naturally, were developed to adapt the method for the special task in hand. The chief of these was the use for most of the work of an immersion oil having nearly the same refractive index (1.544) as halite, which is generally the most abundant mineral. In such an oil the halite is almost invisible and most of the potash minerals are conspicuous. Sylvite, for example, which resembles halite in having cubical cleavage, has a much lower index (1.490) than halite and therefore appears to stand out in bold relief from the oil that "flattens" halite, when the mount is properly illuminated with a slanting light.

As in most other research, the practice developed of stating the results more or less quantitatively, always with the frank admission that the figures were mere estimates. Such estimates, even though very rough, are clearly better than a mere list of the minerals found—a fact which became very evident when the attempt was made to interpret the results.

The results of the intensive petrographic study were at first so meager as apparently to support the pessimistic view that if sylvite were found in significant amount it would only be by lucky chance. There is not time to relate the developments that led to a far different and more gratifying conclusion, but the case as it appears at this date may now be outlined. First let it be said that the cores have honestly repaid their debt to the cuttings, for the evidence by which the value of the cuttings must be determined was obtained by comparing churn-drill cuttings with cores taken as nearby as possible.

The most direct possible evidence was obtained by comparison of the cuttings from the Empire-Martin No. 1 well—an unsuccessful test for oil—with the 17th Government core test. These two wells are not merely close together: they almost coincide. By an arrangement with the company the oil well was plugged back to the 1563-foot level and coring begun at that level by means of an offset. The coring went down to a depth of 2825 feet; the oil-well had gone to 3400 feet. We thus had a core and a set of cuttings that virtually came from the same well. The core gave moderately good showings of carnallite and sylvite, and at the bottom of the sylvite zone there was about 2 feet of nearly solid langbeinite. The cuttings had first been examined with a binocular, and langbeinite but no sylvite had thus been found.

Examination with the petrographic microscope revealed abundant langbeinite, of course, but it also revealed sylvite in quantities exceeding 1 per cent in many samples through almost exactly the same range as the sylvite found in the core. Above the known sylvite, moreover, several samples contained particles of potassium chloride, believed most probably to have been derived from carnallite. The Empire-Martin well had therefore proved the following facts:

1. Sylvite in readily detectable quantity may survive in the cuttings from beds that contain only moderate amounts of sylvite.

2. The binocular is not to be relied upon for finding sylvite.
3. Weak showings of KCl in cuttings do not necessarily represent sylvite.

The direct evidence derived from the Empire-Martin well is supported by a rather small but wholly consistent body of circumstantial evidence, supplied by the few oil wells that lie near diamond-drilled wells that have cut sylvite-bearing beds. All these without exception yield sylvite to the amount of about 1 per cent or more in at least one sample, and most of them in several samples.

One of these wells, indeed—the Snowden & McSweeney Co.'s Lawrence No. 1—yielded cuttings of sensational richness, purporting to represent 30 feet of the bore. It was because of this showing that the 23d Government core test was drilled close by. The core, strange as it may seem, showed far less sylvite than the cuttings, though it did show a bed that probably can be mined commercially. It seems probable, as suggested by Mr. Lang, that the cuttings were enriched by caving from the richest bed, which was readily corroded by the drilling water because of its very richness. It thus appears that, although cuttings in general will probably contain less sylvite per pound than the core from the same beds, they may sometimes give rise to oversanguine predictions.

It now seems pretty safe to venture the following statement: If the cuttings taken at 10-foot intervals from a churn-drilled well, properly examined, fail to show at least 2 per cent of sylvite in some one sample, it is not probable that the well has passed through any layer containing enough sylvite to be classed

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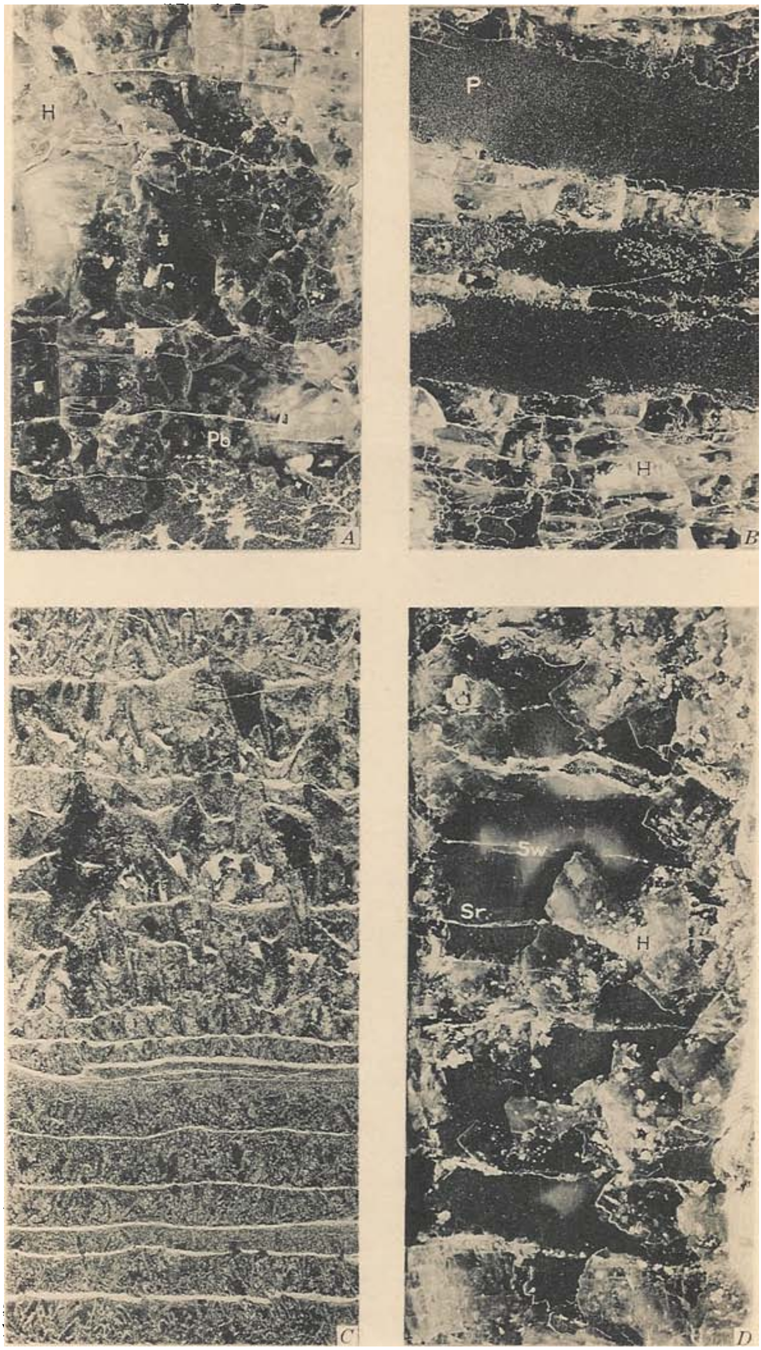
EXPLANATION OF PLATE VIII

A. A core of halite (H) containing prominent blebs of red polyhalite (Pb). The dark areas of halite crystals appear so because the bounding growths of mossy polyhalite blebs exclude light. The whitish areas are halite crystals relatively free of polyhalite blebs. From a depth of 1491 feet in the 5th Government potash test, Crockett County, Texas.

B. A core of fine-grained red polyhalite bands (P) in halite (H). Beds many feet thick are composed of massive polyhalite of this character. From a depth of 1211 feet in the 5th Government potash test, Crockett County, Texas.

C. A polished section of core illustrating graphic and banded structure. The white horizontal layers are magnesitic clay; the remaining portion of the core is polyhalite. The vertical growths between and across the white bands were gypsum crystals, now altered to polyhalite. The outlines of the swallowtail gypsum twins are plainly recognizable. From a depth of 1305 feet in the 4th Government potash test, Ector County, Texas.

D. A polished section of core showing the relationship between halite (H) and red (Sr) and white (Sw) sylvite. The red sylvite is caused by minute inclusions of hematite plates and needles. Where crystals of sylvite are colored both red and white, the red border always surrounds the white zone. A core with this proportion of sylvite and halite contains the equivalent of about 25 per cent of K_2O.


H
Pb
A
P
H
B
C
Sw
Sr
H
D

as "potash reserve." [The conservation branch of the Geological Survey, in calculating present reserves, uses the average grade of salts mined in Germany—beds having a minimum content of 14 per cent K_2O—and a minimum thickness of 4 feet.]

Of course, commercial showings of sylvite are not all that we are to look for in cuttings. Polyhalite beds of exceptional thickness may be found with their aid. A slight showing of authentic sylvite, of carnallite, of blue halite, or of langbeinite may one day tell us that we are on the verge of a rich potash area. Langbeinite in particular is of great interest because most of that which has hitherto been found occurs near the level of the lowest sylvite; unfortunately it is not co-extensive with sylvite. Despite the hygroscopic nature of carnallite, grains of it have been found in a few samples. Evidently these had been preserved because they had become coated with impervious clay.

Finally, negative results may now be taken, we believe, at something like their face value. The labor spent hitherto in going through hundreds of samples that contained no sylvite has not been lost, for it has pointed to large areas in which it would be futile to make core tests with hope of direct economic results. In the future, moreover, no prospecting for potash should be done without preliminary consideration of all pertinent evidence that may be obtainable from cuttings.

The Government core tests and the churn-drilled wells that have yielded sylvite, carnallite, or langbeinite are tabulated on pages 664 to 668, and their distribution is shown on Figure 32. By combining the results of these tests it has been possible to outline tentatively on the same map the area in which authentic showings of the minerals named have been found. In Figure 33 is shown the position of the saline beds with which the potash minerals are associated, as generalized from available well logs. The positions of several of the Government tests and of the United States Potash Co.'s mine have been projected to the section. Both map and section show that the principal area thus far known to yield sylvite, carnallite, or langbeinite occupies a subordinate basin in the western part of this saline mass. Within this basin, in turn, are still smaller areas which yield the richer salts. The United States Potash Co.'s mine is in one such area; the 23d Government test, which yielded a substantial body of sylvite, is apparently in another; the Potash Co. of America's mine in a third; and an area south of the United States Potash Co.'s holdings constitutes a fourth. Others will doubtless be located as prospecting continues. The economic area in Eddy County, New Mexico, that includes the two mines and most of the private core tests is shown by a broken line on the map, Figure 32.

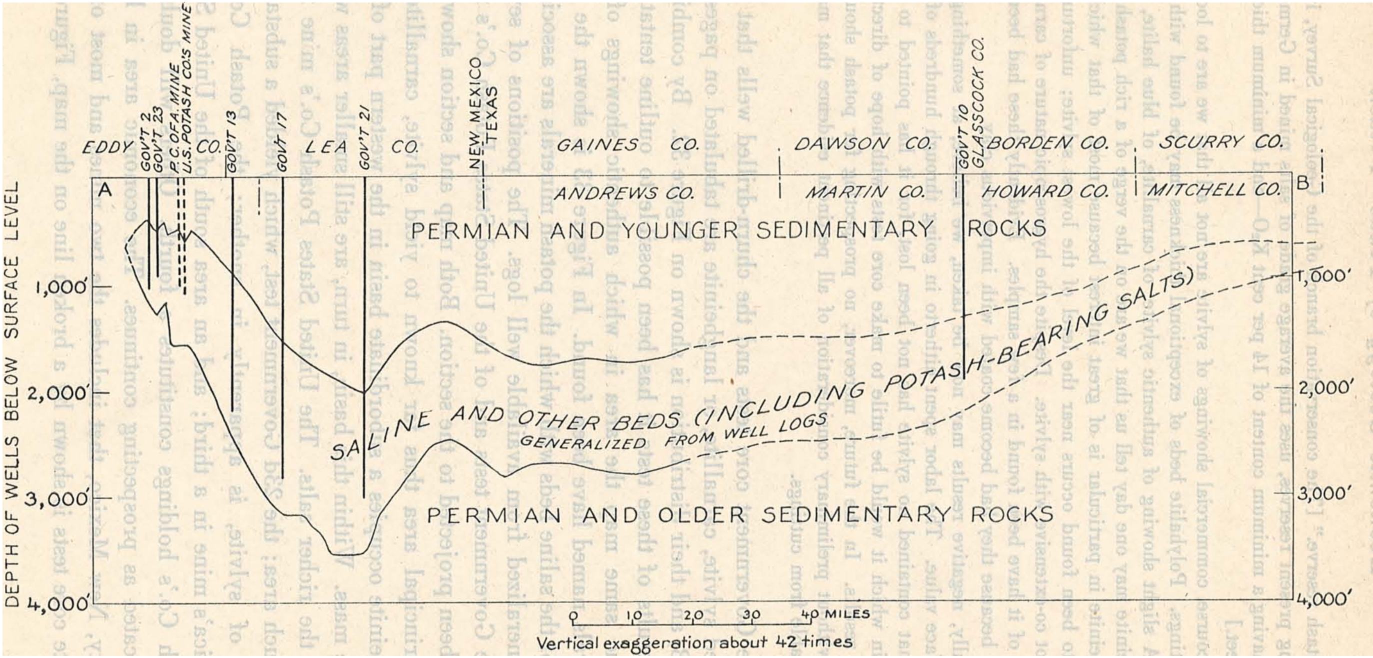


Fig. 33. Section across the Permian basin of New Mexico and Texas, showing the relative position of the potash-bearing saline beds.

The potash possibilities in Utah suggested by the findings in the Crescent-Eagle and some neighboring wells in Grand County (p. 655) have not been sufficiently tested, but from the known structural conditions and the results thus far obtained the prospects for commercial potash development in that state would seem to be less simple and possibly less favorable than in New Mexico or Texas.

Since the end of this successful program the Geological Survey has received no further special appropriations for potash investigations but has continued so far as practicable office and laboratory studies of private potash cores and of cuttings from oil wells in the potash area.

The Bureau of Mines and the Bureau of Soils, however, have received some further appropriations to enable them to investigate the commercial possibilities of some of the less soluble potassium-bearing rocks and minerals, of which abundant supplies are known —especially polyhalite, which is abundant in Texas and New Mexico, and wyomingite, a leucite-bearing lava found in quantity near Superior, Wyoming.

Private organizations under the stimulus of Government activity initiated programs of core drilling in Texas and New Mexico, the results of which were made available to the Geological Survey and Bureau of Mines, thus supplementing the work of these organizations. These private investigations, which have continued since the Government's program was completed, have enabled two companies, the United States Potash Co. and the Potash Co. of America, to block out the bodies of high-grade sylvite that they are now mining in Eddy County, New Mexico. Other companies are engaged in similar exploration but have not yet reached the stage of mining operations.

Summary of Government Potash Tests in New Mexico, Texas, and Utah[a]

No. of test	Location	Beds of possible commercial interest: Thickness Ft.	In.	Approx. depth to top of bed Feet	K_2O Per cent	Minerals present[b]	Remarks
*1st	NW. ¼ sec. 13, T. 17 S., R. 31 E., Eddy County, N. Mex.						Carnallite zone 838–1288 (?) ft.; sylvite 906 (?)–1020 ft. No commercial beds.
*2d	Sec. 14, T. 20 S., R. 29 E., Eddy County, N. Mex.	2 2	8 5	486 810	10.50 13.94	P, A, H, K P, H, Cl, M	Sylvite at 392–394, 502–505, 511–515 ft.; carnallite at 369–371, 440–441, 445–448 ft. No commercial beds.
3d	SW. ¼ sec. 34, T. 22 S., R. 30 E., Eddy County, N. Mex.	3 2 3 2 2 8	2 3 7 4 11 10	868 951 1012 1200 1333 1466	13.50 13.13 12.86 12.88 9.33 11.08	P, H, Cl P, A, H P (white), H, A P, H P, H P, H, A	18% core loss, greatest for all Government tests. Unrecovered portions of core may have contained soluble potash salts.
4th	Sec. 7, Blk. B-16, P. S. L., Ector County, Tex., near Metz station on T. & P. Ry.	3 2 3 2	3 11 8	1309 1636 1936 1942	10.30 13.10 13.54 11.87	P, H P, H, A P, H P, H, A	A 2-ft. 10-in. bed of halite lies between the 3 ft. 11 in. and 2 ft. 8 in. beds of polyhalite.
5th	Harris Bros. ranch, NW. ¼ sec. 16, Blk. HH, G., C. & S. F. Ry. Co. survey, Crockett County, Tex.						5 ft. 8 in. of low-grade polyhalite (5.84% K_2O) at 1370 ft. No commercial beds.
6th	Sun-Burleson lease, sec. 100, T. C. Jones survey, southwestern Upton County, Tex.						2 ft. 3 in. polyhalite (8.24% K_2O) at 682 ft.; 1 ft. 11 in. polyhalite (9.22%) at 901 ft.; 1 ft. 8 in. polyhalite (10.00%) at 1168 ft.; 1 ft. 11 in. polyhalite (8.87%) at 1213 ft.
7th	Roxana - Hughes lease, sec. 4, William Teer survey, southwestern Upton County, Tex.	3	3	848	11.65	P, H	3 ft. 7 in. mainly polyhalite (9.50% K_2O) at 690 ft.; 1 ft. 4 in. polyhalite (12.71%) at 744 ft.; 1 ft. 5 in. polyhalite (12.42%) at 1109 ft.; 1 ft. 11 in. polyhalite (12.04%) at 1157 ft.
8th	Sec. 5, Blk. 14, University land, northwestern Crockett County, Tex.						5 ft. 2 in. partly polyhalite (6.35% K_2O) at 521 ft.; six other beds polyhalite (9.0+%) less than 1 ft. thick.

No. of test	Location	Beds of possible commercial interest: Thickness Ft.	In.	Approx. depth to top of bed Feet	K_2O Per cent	Minerals present[b]	Remarks
9th	NW. ¼ SW. ¼ sec. 1, Blk. 2, University land, southwestern Reagan County, Tex.	2		1526	10.85	P, H	3 ft. about half polyhalite (8.27% K_2O) including the 2-ft. bed at 1526 ft.; 2 ft. 3 in. polyhalite (7.62%) at 1310 ft.
10th	Houston ranch, NE. ¼ sec. 14, Blk. 35, T. 2 S., T. & P. RR. Co. survey, Glasscock County, Tex.						4 ft. 3 in. partly polyhalite (5.88% K_2O) at about 1373 ft. A dozen or more beds polyhalite, none commercial.
11th	Waddell ranch, SE. ¼ sec. 3, Blk. B-25, Crane County, Tex.	4	3	1659	9.82	P, A, H, Cl	Includes 2 ft. 5 in. polyhalite (11.26% K_2O); other beds include 3 ft. 6 in. polyhalite (6.8%) at 1313 ft.; 2 ft. 5 in. polyhalite (11.71%) at 1779 ft.; 2 beds polyhalite with 3 ft. 4 in. salt between give total polyhalite 5 ft. 9 in. (8.36%) at 2010 ft.
*12th	Leeman ranch, sec. 33, Blk. 75, western side Winkler County, Tex.	6		2257	10.63	P, A	Carnallite zone of 319 ft. below 1334 ft. Sylvite with carnallite between 1354 and 1355 ft.; 9 ft. 8 in. polyhalite (7.24% K_2O) at 2267 ft.
		3		2737	10.65	P, H, A	
*13th	Sec. 5, T. 24 S., R. 31 E., Eddy County, N. Mex.	2	1	829	13.36	P, H	8-ft. bed contains 3 ft. 3 in. polyhalite (15.10% K_2O) at 1408 ft. Sylvite and langbeinite zone between 1631 and 1723 ft.
		2	2	1099	10.02	P, H, A, M	
		2	10	1189	11.78	P, H	
		2	1	1382	11.40	P, H, M, Cl	
		8		1406	12.02	P, H, M, Cl, A	
		2	5	1476	12.80	P, H, M	
		2	4	1600	10.61	P, A, H, M	
		3	3	2102	12.05	P, A	
14th	SW. ¼ SE. ¼ sec. 1, T. 26 S., R. 32 E., Lea County, N. Mex.	2	2	1533	12.01	P, H	6 ft. 5 in. bed includes at 1662 ft. 4 in. a 2 ft. 3 in. bed polyhalite (14.03% K_2O).
		6	5	1658	12.04	P, H, A, M, Cl	
		3	10	1741	13.43	P, H	
		3	2	1786	11.19	P, H, A, M	
		2	6	1865	10.21	P, A	
		3	3	2027	12.89	P, H, Cl	
15th	NE. ¼ sec. 34, T. 21 S., R. 29 E., Eddy County, N. Mex.	2	7	941	10.70	P, H, A	2 ft. 9 in. polyhalite (9.85% K_2O) at 712 ft. Numerous other poorer beds polyhalite.

No. of test	Location	Beds of possible commercial interest: Thickness Ft	In	Approx. depth to top of bed Feet	K_2O Per cent	Minerals present[a]	Remarks
16th	SE. ¼ sec. 12, T. 14 S., R. 28 E., Chaves County, N. Mex.	2	8	373	12.10	P, H, Cl, K	
*17th	SW. ¼ NE. ¼ sec. 28, T. 20 S., R. 33 E., Lea County, N. Mex.	4		2356	11.35	S, H, P, C, Cl	The 4-ft. bed includes 2 ft. sylvite, halite, polyhalite, carnallite (15.25% K_2O); the 3-ft. bed includes 11 in. langbeinite (20.63%). Carnallite ranges through 721 ft. from 1736 ft.; sylvite ranges through 191 ft. from 2279 ft.; langbeinite ranges through 26 ft. from 2514 ft.; 1 ft. langbeinite, halite, etc., at 2524 ft. contains 20% K_2O.
		2	7	2385	10.32	P, H, A, S, K	
		7	10	2407	9.12	H, C, Cl	
		3	9	2523	8.97	L, H, P, Cl	
		2	10	2610	13.85	P, H	
*18th	Leeman ranch, SW. ¼ sec. 5, Blk. 28, Public School Land, Loving County, Tex.	1	6	1441	13.35	A, H, S, C, K	A 40-ft. interval containing carnallite begins at 1412 ft.; a sylvite interval of 30 ft. begins at 1426 ft. Well not drilled deep enough to test corresponding polyhalite beds at 2257 and 2737 ft. levels in 12th test.
*19th	Sec. 31, T. 26 S., R. 35 E., Lea County, N. Mex.						Carnallite zone of 250 ft. beginning at 1541 ft.: 4 ft. bed halite, polyhalite, carnallite, etc. (6.98% K_2O) at 1788 ft.; 3 ft. white polyhalite, etc. (7.76%) at 1986 ft.; sylvite at 1541 ft. continues for 216 ft.
20th	Sec. 3, T. 23 S., R. 32 E., Lea County, N. Mex.	2	3	1832	12.93	P, A, H, Cl	3 ft. 4 in. polyhalite, etc. (6.62% K_2O) at 1947 ft.; 2 ft. 6 in. polyhalite, etc. (6.08%) at 1996 ft.; 2 ft. 4 in. polyhalite, etc. (9.17%) at 2008 ft.; 3 ft. polyhalite, etc. (9.80%) at 2088 ft.; 3 ft. polyhalite, etc. (7.43%) at 2135 ft.; 8 ft. 3 in. polyhalite, etc. (5.95%) at 2178 ft.
		3		2284	13.08	P, H, A	
		4	3	2298	9.55	P, Cl, A	

No. of test	Location	Beds of possible commercial interest: Thickness Ft.	In.	Approx. depth to top of bed Feet	K_2O Per cent	Minerals present[b]	Remarks
*21st	SE. ¼ sec. 11, T. 21 S., R. 34 E., Lea County, N. Mex.	5		2553	8.89	P, H, A	Carnallite occurs at intervals through 222 ft. of beds below 2225 ft. At 2739 ft. a 2-ft. bed (4.44% K_2O) contains polyhalite, leonite, langbeinite, kieserite, halite, clay. A 20-ft. zone of langbeinite begins at 2721 ft. Beds at 2760 and 2763 ft. separated by 7 in. of anhydrite, etc., average 11.54% K_2O
		2	8	2760	13.42	P, A	
		2	7	2763	12.20	P, H	
		2	8	2814	12.20	P, H	
22d	SE. ¼ sec. 26, T. 23 S., R. 30 E., Eddy County, N. Mex.	2		638	10.65	P, H	2 ft. 6 in. of polyhalite (11.65% K_2O) at 1175 ft. Upper sylvite zone (20 ft.) at 1215 ft. The 3 ft. 9 in. bed at 1219 ft. includes 9 in. with 21.90% K_2O; lower sylvite zone (30 ft.) at 1409 ft. contains langbeinite throughout.
		2	7	682	12.63	P, H	
		2	1	1152	13.62	P, H, Cl	
		4	4	1175	10.91	P, A, H, Cl	
		3	9	1219	17.72	H, S, Cl, Ka, Le, P, M	
		2	11	1308	10.70	P, A, H, Cl	
		3		1363	11.60	P, H	
		2	2	1501	12.43	P, H, Cl	
		1	11	1565	11.48	P, H, Cl	
*23d	NW. ¼ sec. 35, T. 20 S., R. 29 E., Eddy County, N. Mex.	5	11	623	11.52	P, A, H	Both carnallite and sylvite occur at 517 ft. Carnallite continues to reappear for 180 ft. to 714 ft. Sylvite occurs at intervals to 697 ft.
		5		686	8.80	H, S, Cl	
		5		691	30.75	H, S, Cl	
*24th	SE. ¼ sec. 13, T. 23 S., R. 20 E., Grand County, Utah.						Core chiefly halite; a little scattered polyhalite: sylvite at 1191 and 1442 ft. No commercial beds.

[a]For details of Government tests see pages 693 to 623. Tests marked * have yielded sylvite, carnallite, or langbeinite.

[b]P, polyhalite; A, anhydrite; H, halite; K, kieserite; S, sylvite; C, carnallite; Cl, clay; L, langbeinite; M, magnesite; Ka, kainite; Le, leonite.

Oil and gas tests in New Mexico, cuttings from which have yielded sylvite, carnallite, or langbeinite

Name of well	Location
Snowden & McSweeney-McNutt No. 1	NE. ¼ SW. ¼ sec. 4, T. 21 S., R. 30 E., Eddy County.
Ohio-Workman No. 1	SW. ¼ sec. 13, T. 22 S., R. 29 E., Eddy County.
Marland-Hale No. 1	Sec. 11, T. 20 S., R. 30 E., Eddy County.
Getty-Nicholas No. 1	Sec. 25, T. 20 S., R. 29 E., Eddy County.
Snowden & McSweeney-Lawrence No. 1	Sec. 35, T. 20 S., R. 29 E., Eddy County.
Empire-State I-C	Sec. 12, T. 21 S., R. 34 E., Lea County.
Gypsy-Humphreys No. 1	NW. ¼ SW. ¼ sec. 25, T. 25 S., R. 36 E., Lea County.
Empire-Martin No. 1	SW. ¼ SE. ¼ sec. 28, T. 20 S., R. 33 E., Lea County.
Texas-Humphreys No. 1	Sec. 18, T. 20 S., R. 32 E., Lea County.
Texas-Lynch No. 1	Sec. 34, T. 20 S., R. 34 E., Lea County.
Snowden & McSweeney-State No. 1	NW. ¼ sec. 1, T. 21 S., R. 33 E., Lea County.
Amerada-State No. 1	Northwestern corner lot 10, sec. 1, T. 21 S., R. 33 E., Lea County.
Cranfill & Reynolds-State No. 1-D	Southeastern corner lot 6, sec. 3, T. 21 S., R. 33 E., Lea County.
Continental-A. E. Meyer No. 1	SW. ¼ SW. ¼ sec. 17, T. 21 S., R. 36 E., Lea County.
Continental-Wm. Meyer No. 1	Sec. 28, T. 22 S., R. 36 E., Lea County.
Barnsdall-Bronson No. 1	SE. ¼ sec. 28, T. 16 S., R. 38 E., Lea County.
National Securities-T. A. Linam No. 1	Sec. 33, T. 18 S., R. 37 E., Lea County.
Marland-Gardner No. 1	Sec. 24, T. 23 S., R. 31 E., Eddy County.

None of the cuttings from oil wells drilled in Texas[27] have thus far yielded showings of sylvite, carnallite, or langbeinite such as have been found in the wells listed above. Most of them, however, have shown greater or less amounts of polyhalite. A list of Texas wells, cuttings from which, studied in the Geological Survey, have furnished favorable showings of potash, is given on pages 824–832.

PRIVATE CORE TESTS

Texas.—Early efforts at core drilling for potash in the Texas area were unsuccessful. Stock-promotion and land-leasing enterprises were rife. In 1925–27 two core tests were made on the O. P. Jones

[27]Previous announcements of discoveries of sylvite and langbeinite in the Skelly-Leeman well, in Winkler County, have been found upon reexamination of evidence to be erroneous.

ranch, in southwestern Midland County, by the Standard Potash Co. (now the Texas Potash Corporation of Dallas). These wells are about 3 miles apart. The first was core-drilled from the surface to a depth of 2111 feet except for short intervals in which a fishtail bit was used. The second was drilled by rotary, except for occasional coring, to 1658 feet, below which the diamond drill was used to 2617 feet. Other wells have been drilled in the county by standard tools, and two of these reached depths of 4478 and 4980 feet.

The cores and cuttings from the two wells drilled in 1925–27 have been intensively studied by Sellards and Schoch[28] of the Texas Bureau. These authors report that in well 2 at depths between 1979 and 1989 or 1991 feet the core revealed soluble potash minerals associated with anhydrite. In the first well, through lack of proper drilling solutions, the corresponding part of the core was not recovered, though some enrichment of the drilling solution by potash was noted. Even in the core from well 2 there were considerable losses in this zone, so that its thickness and composition are not accurately known. The pieces of soluble salt recovered, some of which were as much as 1½ inches in diameter, were of a deep red color, were completely soluble, and contained "as received" the equivalent of 13.5 per cent of K_2O—much more than the remainder of the core. Optical examination of this part of the core showed anhydrite and carnallite to be the chief minerals, though there were also suggestions of very small amounts of kainite, sylvite, and some other minerals. Polyhalite layers were recognized in both wells, and on the basis of these layers, together with some beds of anhydrite, Sellards made certain correlations between the two wells. The polyhalite beds. however, were found at depths greater than 1900 feet.

There have been intermittent efforts to exploit this area for potash, but, in the writers' opinion, the available data are insufficient and the potash showings too poor to justify the sinking of shafts.

New Mexico.—The private core drilling in New Mexico has thus far been confined mostly to an area comprising about 120 square miles and lying 15 to 25 miles east and northeast of Carlsbad, in Eddy County. Three test holes, however, have been drilled west

[28]Sellards, E. H., and Schoch, E. P., Core drill tests for potash in Midland County, Texas: Univ. Texas Bull. 2801 pp. 159-201, 1928

of Pecos River, and one in Lea County. In all some 64 core tests have been made by 7 companies or individual operators—the United States Potash Co. (28 tests), the Potash Co. of America (17 tests), the New Mexico Potash & Chemical Co. (7 tests). the General Potash Co. (a Denver group operating in New Mexico) (6 tests), G. A. Kroenlein and associates (1 test), N. C. Christensen-E. J. Longyear Co. (1 test), and the Gypsy Oil Co. (4 tests). Sylvite has been found in most of these tests, in several of them in beds 4 to 10 feet or more thick and containing the equivalent of 14 to 30 per cent of K_2O. The richest sylvite deposit found was in a bed 2 feet 3 inches thick, which contained the equivalent of 51.8 per cent of K_2O. These beds lie mostly within a range of 500 to 1200 feet below the surface. Polyhalite beds were cut in all the tests, and the principal beds ranged from 3 to 10 feet in thickness and from 10 to nearly 15 per cent in potash content. Langbeinite in possibly commercial quantities, carnallite, and other potash-bearing minerals were also recognized in greater or less amounts. The results of this core drilling have led to the opening of two mines, as more fully described on pages 671–673.

Drilling solution.—In prospecting only for polyhalite a concentrated solution of sodium chloride is all that is necessary, but if soluble chloride minerals are expected a restraining solution is essential for good core recovery. Badly etched cores make sampling difficult if not impossible. The solution used in drilling most of the Government core tests consisted of a saturated solution of sodium chloride to which was added 3 pounds of magnesium chloride per gallon. Preheating of the solution was tried on the first and second tests. Later attempts were made to obtain potassium salts for addition to the drilling solution, but this procedure was not incorporated in the drilling contracts until the final year, and it showed no marked improvement. Good drilling technique is as essential to satisfactory core recovery as a balanced drilling solution.

In the private core tests the best results were obtained by using a preheated saturated solution of crude sodium and potassium salts to which magnesium chloride was added.

POTASH MINING

Two companies are now mining potash in Eddy County, New Mexico—the United States Potash Co. and the Potash Co. of America.

United States Potash Co.—In 1926 the Snowden & McSweeney Co., spurred by the discovery of sylvite in the cuttings from one of its oil tests, embarked upon a campaign of core drilling for potash. The American Potash Co. (subsequently the United States Potash Co.) was organized as a subsidiary to carry on this work. (See Pl. VI, B, and Pl. VII.) After blocking out for lease a suitable portion of the area tested and leasing 7680 acres of Government land. this company in December, 1929, began sinking a shaft, which was completed about a year later,[29] the first trial shipment being made in January, 1931. A 4-compartment shaft, 1062 feet deep, was sunk 80 feet below the mine workings to provide an ore pocket and opportunity for skip loading. About 50 gallons of water a minute was struck in the upper formations; a water tunnel was driven nearly around the shaft, and a sump and pump were placed in it. Gas high in nitrogen, with appreciable quantities of methane and hydrogen and under heavy pressure, was encountered when certain polyhalite beds were cut, but the pressure was soon dissipated after the round was shot.

Shaft 2, about 2000 feet south of shaft 1, was begun in July, 1932, and sunk to a depth of 955 feet. In June, 1933, it was connected to the main south entries from the first shaft, thereby providing better ventilation and increasing the hoisting capacity of the mine. In sinking it the water-bearing zones were cemented off. Smith[30] describes the mining and refining operations as follows:

> All projected developments of the United States Potash Co. are laid out north and south, and east and west. The mine is laid out on a double-entry system, with rooms and pillars or blocks having dimensions calling for an extraction of 60 and 75 per cent respectively on first mining. The rooms and blocks are 40 feet wide with 40-foot pillars. A 150-foot barrier pillar is left along each side of the main entries. The entries are driven 20 feet wide, leaving a 50-foot chain pillar between them. Rooms are 300 feet long. The salt is undercut with a

[29]Smith, H. I., Three and a quarter centuries of the potash industry in America: Eng. and Min. Jour., vol. 134. pp. 514–518, 1933; Potash development in southeastern New Mexico: Amer. Inst Min. Eng., Contr. 52. June, 1933.

[30]Smith, H. I., Potash development in southeastern New Mexico: Amer. Inst Min. Eng., Contr 52. pp. 10–12, 1933.

Sullivan chaincutting machine. and the holes are drilled out with airpunching machines. * * * The salt shoots with difficulty, requiring three holes above the undercut within the 9-foot height. Holes are spaced about 4½ feet apart along the face. The salt is loaded with a scraper loader. Three-ton cars with a track gage of 24 inches are in use. The salt is dumped into an ore pocket at the shaft bottom and hoisted by skip. The headframe * * * is 110 feet high and contains an ore bin of 250 tons capacity. The salt is hauled over a narrow-gage railroad to a refinery. Manure salts are shipped either as ground run of mine or enriched with refined salts to the grade desired. * * *

The first carload of natural soluble potash minerals produced in the United States was mined by the United States Potash Co. and shipped January 10, 1931, to California. This and other shipments were used in refining experiments and the results used as the basis for the design of the refinery constructed about 16 miles from the mine and in proximity to the Pecos River. * * * The refinery * * * is connected by a 5-mile standard-gage track with the Atchison, Topeka & Santa Fe Railway at Loving, New Mexico. * * *

Essentially the refining consists of crushing the salts, dissolving the sylvite in hot water, and precipitating the potassium chloride by cooling. When heated a saturated solution at normal temperature will drop out some of the sodium chloride and take up potassium chloride. On cooling the reverse action occurs, so that sodium chloride does not tend to drop out with the potassium chloride.

Construction of the refinery of the United States Potash Co. was started early in April, 1932, and completed September 13, 1932. A trial run was made the next day, and production for sale started on September 17. The plant, designed for a production of 100 tons a day, is turning out considerably more than that. The output is said to contain 99.5 per cent of potassium chloride and to be suitable for the chemical as well as the fertilizer trade.

The great advantage of the New Mexico deposits over foreign salts is their relative freedom from magnesium salts, to which is attributed their lessened tendency to cake in storage, and the more important economic fact that 2 tons of salts mined in New Mexico will produce 1 ton of refined salts of a grade requiring 3 or 4 tons of French or German salts and about 5 tons of Spanish salts.

Potash Co. of America.—In 1931 the Potash Co. of America began exploration of a tract lying generally north-northwest of the property of the United States Potash Co. and more or less contiguous with it. This company made 18 core test holes in three townships, blocked out a workable deposit, and leased about 7680 acres of Government land. In February, 1933, the company began sinking a shaft about 7 miles north of shaft 1 of the United States Potash Co., expecting to reach the potash beds at a depth of about 1000 feet by the end of the year. This objective was substantially realized, and shipments of potash from the new mine began early in 1934. A mill for grinding the salts was completed when these became available in the mine; a highway has been completed to

Potash, the shaft site, and a branch line of the Atchison, Topeka & Santa Fe Railway has been built northeast from La Huerta, just north of Carlsbad, to the mine, a distance of about 20 miles. The general features of the mining are similar to those described for the United States Potash Co.

RESERVES

In the area of 40,000 square miles[31] in the southern portion of the Permian basin tentatively considered as prospective potash territory not more than 30 core tests have been made that may be considered exploratory. This amounts to one test for every 1330 square miles, or three tests to an area equal in size to the State of Connecticut. More than 20 of the Government tests were of this type. They served to delimit the more promising areas for future prospecting and in part to outline the present economic area. In a tract of 120 square miles lying 15 to 25 miles east and northeast of Carlsbad, New Mexico, over 60 development core tests have been put down; or an average of two to the square mile. Of this area 33 square miles have been proved to contain commercial deposits of sylvite.

The rich layers disclosed by the tests are numerous and vary in thickness. Smith[32] has distinguished as "beds" some 40 of these. about half lying above a well-defined anhydrite bed or marker and half below. (See fig. 34.)

The sylvite zone in the shaft of the United States Potash Co., which comprises many beds, contains one section 82 feet thick and another 58 feet thick that average about 9 per cent of K_2O. The bottom 10 feet ranges from 25 to 30 per cent of K_2O in the area that is now being mined.

Assuming a minimum content of 14 per cent of K_2O (the average of the German salts) and beds 4 feet or more thick, Smith has estimated that the area of 33 square miles in New Mexico just mentioned contains 100,000,000 tons of potash salts, one-fourth of which contains more than 28 per cent of potash and thus has twice

[31]Mansfield, G. R., and Lang, W. B., Government potash exploration in Texas and New Mexico: Trans. Amer. Inst. Min. Eng., pp. 241–255, 1929.

[32]Smith, H. I., Three and a quarter centuries of the potash industry in America: Eng. and Min. Jour., vol. 134, pp. 516–517, 1933; Potash development in southeastern New Mexico: Amer. Inst. Min. Eng., Contr. 52, pp. 6–7, 1933.

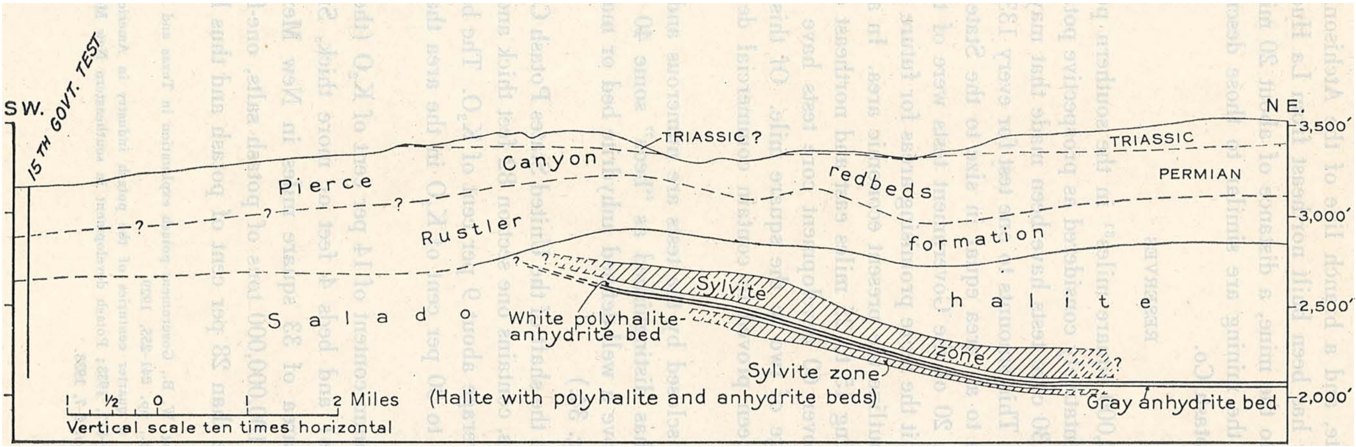


Fig. 34. Section through a sylvite-bearing area in Eddy County, New Mexico. [The term Pierce Canyon redbeds used in this sketch is a formation name recently proposed by W. B. Lang (Bull. Amer. Assoc. Petr. Geol., vol. 19, p. 264, 1935). The term Salado halite was proposed by Lang for the upper salt series in the same publication. The other formation names appearing in this sketch are explained in Volume I, University of Texas Bulletin 3232.—Ed.]

the average richness of the salts mined in Germany. Since this estimate was made additional rich deposits have been found, but no new estimates are available.

This tract is largely Government land, but a considerable area belongs to the State of New Mexico, and a relatively small area is privately owned. All of the proved 33 square miles are under lease or prospecting permit except a small area around the 23d Government core test.

Reserves of polyhalite have not been estimated but are undoubtedly large, as this mineral has been encountered in practically every core-drill hole that has penetrated the salt deposits in the Texas-New Mexico potash area. Smith[33] writes:

> Polyhalite is the most abundant of the potash minerals, both in number of beds and in extent of deposits. However, polyhalite in a single bed over 4 feet thick and containing over 12 per cent of K_2O has not been proved to be continuous over a very large area. One reason for this is that the development of polyhalite has not yet been seriously considered, and as some of the most promising polyhalite deposits lie some distance below the lower sylvite zone, and only a few holes have been cored deeply enough to test these lower beds, more prospecting is needed before any area can be considered proved sufficiently to open a mine solely for polyhalite. The polyhalite beds vary in thickness and in the amount of anhydrite [and halite] present. Within short distances a rich polyhalite bed may change to one with a high percentage of anhydrite, and for this reason closer drilling may be needed than has been required for sylvite before reliable estimates of reserves of polyhalite can be made. There is little doubt of the adequacy of reserves of polyhalite to meet requirements when a demand is developed for this mineral. One of the best polyhalite beds so far found was cut at a depth of 1250 feet in a privately owned well. It is 9 feet thick and averages 13.5 per cent of K_2O.

The 3d Government core test at a depth of 1460 feet encountered a 15½-foot bed of polyhalite, halite, and anhydrite containing 8.84 per cent of K_2O. The lower 8 feet 10 inches contains 11.23 per cent of K_2O.

Langbeinite ($K_2SO_4.2MgSO_4$) has been found in several privately owned wells in New Mexico at minable depth and apparently in beds of sufficient richness and thickness to justify development on proper demand. However, the discovery of this mineral has been incidental to the search for sylvite, and more intensive prospecting

[33]Smith, H. I., Three and a quarter centuries of the potash industry in America: Eng. and Min. Jour., vol. 134, pp. 516–517, 1933.

would be necessary before the nature and amount of its reserves could be adequately stated.

Outlook.—With two producing mines in New Mexico and with the plant of the American Potash & Chemical Corporation at Searles Lake, California, which has been producing high-grade potassium chloride for more than 12 years, the United States already has sufficient productive capacity to meet its requirements of muriate and manure salts at reasonable prices unless foreign producers resort to dumping. As potash fertilizer salts are on the free list there will doubtless continue to be imports on a greater or less scale.

Thus far no attempt has been made by American producers to meet the country's requirements in potassium sulphate. There would seem no reason, however, why this could not be done if sufficient demand should arise. The demand could be met by utilizing polyhalite or langbeinite in one of the processes made available by the United States Bureau of Mines or the Texas Bureau of Industrial Chemistry; or sylvite could be employed with sulphur, to be had as native sulphur, from the Gulf coast or from Reeves and Culberson counties, Texas, or as sulphuric acid potentially available from the smelter at El Paso or in waste gases from some of the oil fields.

The Spanish, Polish, and Russian deposits are sufficiently large and well developed to offset any possible shortage that might occur through future isolation of German or French sources of supply. Thus it seems practically impossible that a potash famine, such as that which existed in the United States during the World War, could again arise.

GEOLOGIC CONDITIONS AFFECTING DEPOSITION OF POTASH IN THE PERMIAN BASIN

Stratigraphic conditions.—The stratigraphy of the Permian basin has been receiving intensive study in recent years, especially by oil company, State, and Federal geologists, and though much detailed work will still be necessary before final conclusions may be reached its broader outlines seem now to be reasonably well understood.[34]

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[34]Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, pp. 140–186, 1932 [1933]. See also Symposium (10 papers) on Pennsylvanian and Permian stratigraphy of southwestern United States: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 883–1063, 1929. Van der Gracht, W. A. J. M., The Permo-Carboniferous

So far as the potash-bearing salts are concerned only brief discussion of stratigraphy is needed here, and the reader is referred to an excellent discussion of the subject by Sellards.[35]

In the area of the Southwest that is of particular interest in the present discussion, an inheritance of the Permian from Pennsylvanian time was a widespread epicontinental sea covering much of western Texas, eastern New Mexico and Colorado, and Oklahoma and Kansas. The Permian beds record the gradual withdrawal southwestward and the final extinction of this sea. One of the major consequences of this withdrawal under the prevailing structural and climatic conditions was the formation of enormous salt bodies. Though salt deposition began early in the Permian (Wellington formation of Kansas) and recurred in successive stages toward the southwest, it was not until the end of Delaware Mountain time that the great accumulation of salines occurred. The "lower salt series," which was deposited upon the Delaware Mountain formation in the Delaware basin and which filled the basin to overflowing, was followed by an "upper salt series" that spread northward and eastward for 150 miles over the rim of the basin. The maximum combined thickness of the salt series exceeds 4000 feet. Overlying the salt series is about 400 feet of anhydrite, dolomitic limestone, sandstone, and red shale of the Rustler formation and an additional 400 feet of a sandy red shale series—the Pierce Canyon redbeds.[36] Subsequently the Triassic redbeds, the Comanche basal sandstones and limestones, the Tertiary sediments of the High Plains, and the Quaternary deposits were superimposed on the older beds. Along the synclinal axis of the main basin, where erosion has been negligible, the overburden above the top of the salt may exceed 3000 feet, but on the western margin of the salt basin, in the southern Pecos Valley of New Mexico, where the overburden was thinner originally, subsequent erosion has reduced this interval to 400 feet.

The Castile formation, which as now interpreted constitutes the lower salt series, is practically devoid of potash, but the Salado (upper salt series), in which polyhalite is distributed throughout

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orogeny of the south-central United States: K. Akad. wetensch. Amsterdam Vers., Afd. natuurk., deel 27, no. 3, 170 pp., 1931. King, P. B., Permian stratigraphy of trans-Pecos Texas: Bull. Geol. Soc. Amer., vol. 45, pp. 697–798, 1934.

[35]Sellards, E. H., and others, *op. cit.*, pp. 180–186.

[36]Lang, W. B., Upper Permian formations of the Delaware Basin of Texas and New Mexico: Bull. Amer. Assoc. Petro. Geol., vol. 19, pp. 262–270, 1935.

in layers and irregular masses, carries in its upper portion the local deposits of potassium chlorides and associated salts of present economic importance. The chloride basins so far found lie in Eddy and Lea counties, New Mexico, and Midland County, Texas. (See p. 661.) All but the one in Texas fall within or along the northern rim of the Delaware basin. These fortuitous circumstances have been of very material help both in prospecting and in mining.

Deposition of the salt series has not been continuous but periodic, and the successive oscillations, either climatic or diastrophic, have resulted in the development of numerous beds of polyhalite. More than 40 have been recognized in the area east of Carlsbad, but such a number is not standard for the basin as a whole. For the same reason the chloride bodies are in many places represented by a succession of sylvite-carnallite beds but of far smaller number.

Structural conditions.—The southern part of the Permian basin is a broad symmetrical geosyncline with a north-south trend. The eastward and westward dips of the beds are gentle and measurable only in feet to the mile. In the southwestern portion is the subsidiary Delaware basin, which interrupts the otherwise continuous westward rise of the strata. About the margin of this subsidiary basin the salt series has been mildly flexed, but nowhere have any salt domes or doming phènomena been observed of other than incipient development and slight dimensions. The rim, however. is chiefly the combined product of structural warping and reef development. Such faulting as may be present is of secondary importance. Other than the fault of 1200-foot throw on the south side of the Amarillo uplift, no other prominent faults affecting the salt series are known to exist in the Permian basin.

POTASH AND ASSOCIATED SALTS IN THE PERMIAN BASIN

Relations to salt series.—In volume the potash-bearing salts form only a fractional part of the upper division of the great salt-bearing series. They are distributed in beds or bands from a fraction of an inch to several feet in thickness and in irregular blebby masses through an interval of 1500 feet or more of salt and associated beds. They are less extensive in the general area of their occurrence than the formation as a whole, for they are cut off successively and unconformably by the overlying Triassic beds where they approach the margins of the basin. (See fig. 34.) Probably few of the potash-bearing beds were laid down originally as such. They seem rather to have been formed by replacement of earlier-formed anhydrite or halite, as shown more fully beyond.

Potash minerals discovered.—The potash-bearing minerals thus far discovered in the region are as follows:

Sylvite, KCl (K, 52.4 per cent, corresponding to 63.2 per cent K_2O; Cl, 47.6 per cent).

Carnallite, $KCl.MgCl_2.6H_2O$ (K, 14.1 per cent, equivalent to 17.0 per cent K_2O; Mg, 8.7 per cent; Cl, 38.2 per cent; H_2O, 39.0 per cent).

Langbeinite, $K_2SO_4.2MgSO_4$ (K_2O, 22.7 per cent; MgO, 19.5 per cent; SO_3, 57.8 per cent).

Polyhalite, $K_2SO_4.MgSO_4.2CaSO_4.2H_2O$ (K_2O, 15.6 per cent; MgO, 6.6 per cent; CaO, 18.6 per cent; SO_3, 53.2 per cent; H_2O, 6.0 per cent).

Leonite, $K_2O.MgO.2SO_3.4H_2O$ (K_2O, 25.7 per cent; MgO, 11.0 per cent; SO_3, 43.7 per cent; H_2O, 19.6 per cent).

Kainite, $KCl.MgSO_4.3H_2O$ (K, 15.7 per cent; MgO, 16.1 per cent; Cl, 14.3 per cent; SO_3, 32.1 per cent; H_2O, 21.8 per cent).

Aphthitalite (glaserite), $(K,Na)_2SO_4$ (K_2O, 42.5 per cent; Na_2O, 9.3 per cent; SO_3, 48.2 per cent.

Sylvite was first discovered in the United States in cuttings from a well in the Markham salt dome, in Matagorda County, Texas, early in 1925. This mineral was shortly afterward noted in cuttings from the Crescent-Eagle well, in Utah, in 1925, and in cuttings from the McNutt No. 1 well, in Eddy County, New Mexico, in the Permian basin, in 1926. The other minerals mentioned were first discovered in the United States in cores taken from wells in the Permian basin, with the exception of carnallite, which was found in cuttings from the Crescent-Eagle well, Utah, in 1924.

Associated minerals.—The potash-bearing minerals of the Permian basin and their associated minerals as represented in various public and private core tests have been described by Schaller and Henderson.[37] The associated minerals identified or recognized by these authors are anhydrite, bloedite, calcite, celestite, clay (varieties not distinguished), dolomite, epsomite, glauberite, gypsum, halite, hematite, kieserite, lueneburgite, magnesite, opal, pyrite, and quartz. In addition F. C. Calkins has identified aphthitalite, which was discovered by W. B. Lang. Kieserite, lueneburgite, and aphthitalite,

[37]Schaller, W. T., and Henderson, E. P., Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Geol. Surv., Bull 833. 124 pp., 1932.

like most of the other potash minerals above enumerated, have their first recorded appearance in the United States in this field. W. B. Lang also recognized the presence of chlorite flakes in several of the cores.

Halite is by far the most abundant mineral, making up at least three-quarters of the saline portion of each core. Anhydrite is next, and after that the clays. Anhydrite, halite, clay, polyhalite, magnesite, and hematite occur in varying quantities in all the cores studied, and all have played important parts in the origin of the potash deposits.

Order of succession.—The study of these potash cores[38] has shown rather definite associations of certain minerals. A typical sequence, repeated many times in the same core, begins with a layer of clay at the bottom, grading upward into anhydrite, on which rests polyhalite. This sequence is followed by halite with a little polyhalite scattered through it ("blebby salt"), and this by halite. Characteristic pairs of minerals, such as clay and magnesite, polyhalite and anhydrite, halite and sylvite, are very common and naturally suggest genetic relations or sequence of formation of the minerals. Some of the minerals occur in sharply defined layers, as well as in intimate admixture, and the same two minerals may show both modes of occurrence within a single piece of core only 2 or 3 inches in diameter and a few inches long.

Hematite coloration.—Hematite occurs as microscopic plates and needles disseminated through many of these saline minerals, imparting to them a greater or less degree of reddish coloration. The formation of hematite may have been connected with bacterial growths. The insoluble residue obtained by dissolving the deeply colored polyhalite in hot water has stringy structure, and ignition of this residue suggests an organic origin. The nature of such supposed bacterial or algal growths has not been studied.

Successive replacements.—The study of the cores by Schaller and Henderson[39] shows very definite evidence of widespread replacement of some of the minerals of the potash sequence. The most noteworthy examples are to be found in the relations of polyhalite to anhydrite and halite. The first mineral formed, according to

[38]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp. 8, 11.
[39]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp. 14–76.

these authors, was anhydrite, which was stable in the dilute brines from which it was precipitated. As the concentration of the brines was greatly increased by further evaporation the anhydrite was no longer inert to the supernatant brines, which were richer in magnesium and potassium. The greater concentration of magnesium and potassium salts in the brines caused them to react with the already formed anhydrite and possibly other minerals to form polyhalite.

One set of changes of which evidence was frequently observed involved the intermediate development of gypsum, of which no trace now remains save the crystal form, which is definitely preserved. The gypsum is now replaced by halite, much of which in turn is partly or wholly replaced by polyhalite. Bands of polyhalite have grown by the conjunction of masses formed by replacement in this way. (See Pl. VIII, C.) Another type of replacement has been the sporadic development of spherulites of polyhalite within the anhydrite mass. These by increased growth and coalition have developed bands of polyhalite.

Polyhalite blebs have grown through direct replacement of halite by the reaction of the concentrated brine with halite along fracture and cleavage planes. These blebs by subsequent enlargement have united into bands or beds.

Doubtless beds of polyhalite may have been formed by direct precipitation from the mother liquor, but the examples of replacement are so numerous that this process must have had an important if not the leading part in the development of polyhalite.

Replacement of halite or other minerals by sylvite or carnallite is not so readily recognized, but these minerals have been found in relations where replacement seems the probable explanation, and both of them, as well as polyhalite, have been found in more than one generation at some places.

Complexity of depositional history.—The great thickness of the salt series, the great number of sequences of beds of clay, anhydrite, polyhalite, and other minerals, and the evidence of widespread replacement activity indicate that the process of desiccation of the Permian basin was long-continued and subject to very numerous interruptions or fluctuations. Some of these were of sufficient duration to permit the accumulation of the rich beds of sylvite and polyhalite previously mentioned. Thus the relatively simple idea, entertained by many in the earlier stages of the potash inquiry, that the best and richest deposits would be found in the central or deep parts of the basin seems not to hold. Instead, the best deposits thus far found seem to lie in marginal subbasins, where changes of relatively minor importance in the large basin were amplified and where desiccation to more advanced stages was more readily possible. Comparable though less advanced conditions of desiccation are perhaps illustrated today by Adji-darja, an embayment on the east side of the Caspian Sea.

SYLVITE

Occurrence and distribution.—The known occurrences of sylvite in the Permian basin are in the two shafts and in wells, mostly core tests, within the area of 3000 square miles in southeastern New Mexico and adjoining parts of western Texas shown on Figure 32. Within this area the distribution of the sylvite is fairly wide, so far as present borings show, but the richer beds are localized in four known minor areas, which have been prospected in some detail and which are surrounded by barren or relatively barren ground. Such prospecting as has been done outside of these areas has not thus far led to any very encouraging results, but it is quite possible that other rich localities may be discovered within the general area mentioned.

The main Permian basin lies principally in Texas. Whether other subsidiary basins of the type just discussed lie within it or along its margin is not yet known. The area to be explored is very large, and the prospecting already accomplished is comparatively small in amount and very scattered. Suggestion of one such basin, though at considerable depth, is afforded by the borings in southwestern Midland County that have been described by Sellards and Schoch,[40] though sylvite itself has not been identified in the cores from this locality.

Structural relations.—The producing area east of Carlsbad, New Mexico, is shown in cross section in Figure 34. The Salado halite contains numerous beds of red polyhalite and anhydrite that are not shown. The most significant of these beds for correlation are the

[40]Sellards, E. H., and Schoch, E. P., *op. cit.*

white polyhalite bed about 4 feet thick and a gray anhydrite bed usually about 20 feet below it. The gray anhydrite does not contain potash, but the white polyhalite, in places almost pure, grades laterally into anhydrite that may become as much as 90 per cent of the bed. A thick zone of sylvite lies above the white polyhalite, and below both this zone and the gray anhydrite is another thinner, less extensive, but far richer zone, which is now being mined. Whether these sylvite zones diffuse or lens out is not definitely known, but truncation by erosion of the Salado prior to the deposition of the Rustler definitely limits their extent on the west side. The entire mass dips gently to the south of east. A component of this dip is shown in the section where the white polyhalite descends from 800 feet to 1400 feet within a distance of 6 miles, or at the rate of about 100 feet to the mile. The economic features of these sylvite zones are discussed on pages 669–676.

Mineralogic relations.—The sylvite, KCl(K, 52.4 per cent, corresponding to 63.2 per cent K_2O; Cl, 47.6 per cent), is characteristically reddish brown but may be either colorless or milky white. Its taste, sharper and more biting than that of halite, its violet flame reaction, and its refractive index (1.490; that of halite is 1.54) serve to distinguish it. It is less brittle than halite and tends to flatten out rather than to crush under pressure.

According to Schaller and Henderson[41] there seem to have been two generations of sylvite. One is colorless and the other reddish brown. Not all sylvite that has a similar color is of the same generation, but the colorless variety seems to be the older. In some sections of core the reddish sylvite has developed in the colorless variety along cracks and cleavage planes. (See Pl. VIII, D.) The sylvite is invariably associated with halite, forming a mixture known as sylvinite. Clay is also a fairly constant associate. In many places clay makes up a large percentage of the sylvite-bearing portions of the core, and the sylvite becomes very irregular, yet little or no clay is found embedded in the sylvite itself.

Polyhalite in blebby masses or in bands occurs within the sylvite zones, but the thicker and richer accumulations occur in the upper and lower polyhalite zones.

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[41]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp. 74–76.

Blue halite is in many places scattered through colorless halite associated with sylvite. Thus far it has not been found in any other association within the potash field. Its presence in well cuttings therefore, so far as present experience goes, may be considered presumptive evidence of the occurrence of sylvite at the same locality, even if the sylvite itself should escape detection.

Another fairly constant associate of sylvite in the cores is langbeinite. This mineral is not coextensive with sylvite in distribution. Nevertheless, it has not thus far been found in other association than in the sylvite zone, and, like blue halite, it seems to be a valuable guide in the search for sylvite-bearing areas. Its most prominent occurrence is usually near the bottom of the lower sylvite zone, but it is not confined to that zone.

Another close associate of sylvite in cores and cuttings is lueneburgite, a hydrous phosphoborate of magnesium.

These so-called "guides" are chiefly valuable in their bearing on the possible discovery of new sylvite areas and as aids to exploration.

POLYHALITE

Occurrence and distribution.—Polyhalite, which contains, when pure, 15.6 per cent of K_2O, is next to halite and anhydrite in abundance and is by far the most abundant potash-bearing mineral in the field. The cuttings received in the Geological Survey from most of the oil wells drilled in the western Texas and southeastern New Mexico portion of the Permian salt basin (an area of some 40,000 square miles) have yielded at least some polyhalite. Some beds of nearly pure polyhalite 8 feet thick have been found, and many beds a foot or more thick have been cut by the drill. In addition to forming well-defined beds, polyhalite is present as disseminated blebs throughout much of the halite.

General character.—The detailed mineralogy of polyhalite has been discussed by Schaller and Henderson.[42] For present purposes it is sufficient to state that the mineral is generally massive, compact, and fine-grained. It has been found in association with all the other minerals previously mentioned. The most common color is perhaps a coral-red, but the mineral is also found ranging from a creamy white or gray (light to dark) through orange, salmon, and brown

[42]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp 50–73.

to deep shades of red. Variations in texture also cause variations in color that are not perceptible to the naked eye but show clearly in a photograph. The texture of much of the polyhalite is very fine grained and gives an almost waxy appearance to the mineral. Locally it is coarser-grained, granular, or more rarely composed of distinct crystals.

Structural relations.—In the area shown in Figure 32, where polyhalite occurs in the sylvite-bearing areas, it tends to form beds or bands distributed through relatively thick zones that lie respectively above and below the sylvite zones and are accordingly designated the upper and lower polyhalite zones. (See fig. 34.) The white polyhalite between the two sylvite zones has already been mentioned. In other parts of the field, where information is more scattered, no special structural relations have been observed except that the beds appear to lie nearly horizontal or to have only gentle dips and to be extensive.

Relations to anhydrite and halite.—The intimate relations of polyhalite to anhydrite and halite have been pointed out above. (See Pl. VIII, *A*, *B*.). One further aspect of these relations needs emphasis. This is the tendency of polyhalite beds to change laterally by increase in amount of one or the other of these associated minerals into leaner beds or perhaps completely into anhydrite or halite within short distances and then possibly to reverse the process. This has been noted particularly in the white polyhalite that lies between the two sylvite zones in southeastern New Mexico. Indeed, such changes may be observed within the width of a section of core, 2 or 3 inches. It is therefore not safe to infer that apparently corresponding beds in neighboring wells continue with the same thickness and quality beneath the intervening area. Smith has recognized this fact in discussing the reserves of polyhalite. (See pp. 673–676.)

Technologic studies of polyhalite.—The abundance and mining accessibility of polyhalite have made it an attractive subject of investigation with a view to its commercial utilization. Both the Texas Bureau of Industrial Chemistry and the United States Bureau of Mines have worked on these problems.[43] The results seem to

[43]Schoch, E. P., U. S. patents 1794551, 1794552, 1794553, March 3, 1931; 1924519, Aug. 29, 1933.

Wroth, J. S Commercial possibilities of the Texas-New Mexico potash deposits: U. S Bur. Mines, Bull. 316, 144 pp., 1930.

show that ground polyhalite can be used without treatment as a fertilizer within an area whose radius is controlled by cost of transportation. Polyhalite can also be used in the manufacture of potassium sulphate and "sulphate of potash magnesia" under similar limitations but in broader areas when demand for these products increases. If interest in magnesium and magnesium products becomes sufficiently active, polyhalite will serve as an abundant source for these materials, and processes are at hand for their extraction. Meanwhile, as the present demand is more largely for the chloride salts, the development of an industry based on polyhalite must await a more favorable commercial opportunity.

LANGBEINITE

Occurrence and distribution.—Langbeinite, $K_2SO_4.2MgSO_4$, has thus far not been found except as already noted in the sylvite areas in New Mexico. Thus it is not yet known from Texas. Its mineralogy has been discussed by Schaller and Henderson.[44] It occurs in both massive, granular form and in distinct tetrahedral crystals, showing triangular outlines on the surfaces of cores. Some massive colorless varieties resemble granular quartz in their lack of color,

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Storch, H. H., and Clarke, Loyal, A study of the properties of Texas polyhalite pertaining to the extraction of potash: U. S. Bur. Mines, Rept. Inv. 3002, 19 pp., 4 figs., 1930.

Storch, H. H., A study of the properties of Texas polyhalite pertaining to the extraction of potash, pt. 2, The rate of decomposition of polyhalite by water and by saturated sodium chloride solutions: U. S. Bur. Mines, Rept. Inv. 3032, 11 pp., 3 figs., 1930.

Clarke, Loyal, Davidson, J. M., and Storch, H. H., A study of the properties of polyhalite pertaining to the extraction of potash, pt. 3, Calcination of polyhalite in a laboratory-sized rotary kiln: U. S. Bur. Mines, Rept. Inv. 3061, 12 pp., 2 figs., 1931.

Storch, H. H., and Fraas, F., A study of the properties of Texas polyhalite pertaining to the extraction of potash, pt. 4, Experiments on the production of potassium chloride, by the evaporation of leach liquors from decomposition of uncalcined polyhalite by boiling saturated sodium chloride solutions: U. S. Bur. Mines, Rept. Inv. 3062, 7 pp., 1931.

Storch, H. H., and Fragen, N., A study of the properties of Texas-New Mexico polyhalite pertaining to the extraction of potash, pt. 5, Suggested processes for the production of syngenite and by-product magnesia: U. S. Bur. Mines, Rept. Inv. 3116, 19 pp., 2 figs., 1931.

Conley, J. E., Fraas, F., and Davidson, J. M., A study of the properties of Texas polyhalite pertaining to the extraction of potash, pt. 6, A study of the calcination of polyhalite in a 6 by 132 inch rotary kiln; Density measurements as control tests for efficiency of calcination: U. S. Bur. Mines, Rept. Inv. 3167, 17 pp., 7 figs., 1932.

Conley, J. E., and Fraas, F., A study of the properties of Texas-New Mexico polyhalite pertaining to the extraction of potash, pt. 7, Effect of particle size, sodium chloride concentration, and temperature upon hot extraction by a multistage process: U. S. Bur. Mines. Rept. Inv. 3210, 29 pp., 5 figs., 1933.

Davidson, J. M., and Fraas, F., A study of the properties of Texas-New Mexico polyhalite pertaining to the extraction of potash, pt. 8, Removal of sodium chloride from crude polyhalite by washing: U. S. Bur. Mines, Rept. Inv. 3237, 25 pp., 6 figs., 1934.

[44]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp. 41–44.

transparency, and glassy luster. Most langbeinite, however, has a distinctive pink color. It is the "hardest-looking" of the saline minerals of the potash field and has a conchoidal or irregular fracture with no cleavage.

Thickness and potash content.—The greatest observed vertical range for langbeinite is about 100 feet in the 13th Government core test. The thickness of beds containing langbeinite ranges from a trace to nearly 14 feet. The thickest bed of possible commercial interest found was in a private core test; this is a 5-foot bed with a potash content of 11.25 per cent.

Associated minerals.—Occasionally beds of nearly pure langbeinite have been encountered. The best of these was an 11-inch bed at a depth of 2524 feet in the 17th Government test, which yielded 20.63 per cent of K_2O. Ordinarily halite, sylvite, and polyhalite occur in the same bed in greater or less amount. Langbeinite may be altered to kieserite or to kainite. The changes may be expressed as follows:

$$\underset{\text{(Langbeinite)}}{K_2SO_4.2MgSO_4} + 2H_2O = \underset{\text{(Kieserite)}}{2MgSO_4.H_2O} + K_2SO_4$$

or

$$\begin{array}{ll} \text{Langbeinite}\ldots\ldots\ldots & K_2|SO_4|.2MgSO_4 \\ \text{Kainite}\ldots\ldots\ldots\ldots & K_2|Cl_2|.2MgSO_4.6H_2O. \end{array}$$

Possible utilization.—Langbeinite occurs at different places within an area comprising at least five or six townships. There is undoubtedly much barren or lean ground with respect to langbeinite within this area, but the known distribution strongly suggests local areas of possibly several square miles which may be underlain by beds thick enough and rich enough to mine if sufficient demand for potassium sulphate should arise. Further prospecting would be necessary before any mining operations were undertaken. The present sulphate demand is met almost wholly by imports, but the quantity used is much less than that of the chlorides on which American producers are chiefly concentrating.

CARNALLITE

Occurrence and distribution.—Carnallite[45] has been found in cores from the 1st, 2d, 12th, 17th, 18th, 21st, and 23d Government tests

[45]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp. 21–23.

and in many private cores. It is massive and compact, showing no crystal faces. The individual crystal units, seen in crushed material under the microscope, are small, few of them exceeding a millimeter across. It occurs most abundantly as small specks and blebs, associated with halite and sylvite, but it also forms narrow seams of the pure mineral, some as much as 4 inches thick, in clay and in other parts of the cores.

Carnallite was recognized in a private core test drilled in southwestern Midland County, Texas. This occurrence has been described by Sellards and Schoch.[46] (See pp. 668–669.)

General properties.—The carnallite from the 1st and 2d Government tests is about colorless, whereas that from the 12th Government test and many of the private cores is dark reddish brown. It is brittle and easily breaks into small pieces with the usual brilliant luster, and the broken pieces show no cleavage faces. Its brilliant luster, bitter taste, and lack of cleavage serve as criteria for its field determination. The mineral readily deliquesces and dissolves in the absorbed moisture. It is readily soluble in the drilling brines composed of sodium and magnesium chlorides, such as were used for many of the tests, and much of the carnallite originally in the cores was thus lost in the drilling operation.

Relations to other minerals.—Some of the irregular masses of carnallite from the 12th Government test, in Loving County, Texas, have a decided vertical extension and in shape and position resemble the vertical growths of halite in anhydrite. These roughly vertical streaks suggest replacement of halite by carnallite similar to that of halite by polyhalite, noted on page 680. In some of the halite from the same test carnallite forms roughly rectangular masses, as if it had filled corresponding cavities (negative crystals) in halite. No definite evidence of replacement of other minerals by carnallite has been noted, but there are strong suggestions that locally it has replaced anhydrite and polyhalite.

Vertical range.—The vertical range of carnallite is much greater than that of sylvite or langbeinite but less than that of polyhalite. Carnallite has been found in both upper and lower polyhalite zones as well as in the two sylvite zones. (See fig. 34.) In the 17th Government test hole, in Eddy County, New Mexico, its total vertical range is about 720 feet.

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[46]Sellards, E. H., and Schoch, E. P., *op. cit.*

Thickness and quality.—The occurrence of carnallite in the cores is far more irregular than that of sylvite, polyhalite, or langbeinite, being largely in the form of blebs. However, there are some enriched zones corresponding roughly to beds, and some of these are of sufficient thickness and richness to deserve mention. For example, in the 17th Government test in the 25-foot interval between depths of 2275 and 2300 feet there is a 3½-foot bed containing an intimate mixture of halite, sylvite, carnallite, leonite, and clay that contains 7.32 per cent of K_2O and a 4-foot 10-inch bed consisting mostly of halite with some carnallite and clay that contains 5.59 per cent of K_2O. The 25-foot interval between depths of 2354 and 2379 feet includes a 2-foot bed that consists of an intimate mixture of halite, sylvite, polyhalite, and carnallite and contains 15.25 per cent of K_2O. This may be combined with adjacent beds to form 4 feet of material carrying 11.35 per cent of K_2O or 5 feet 9 inches of 9.45 per cent material. A 2-foot 6-inch bed containing 7.13 per cent of K_2O is also included in the interval. The core here is much dissolved, and the original beds from which it was cut may have been considerably richer. The 60-foot zone between depths of 2398 and 2458 feet includes a bed 7 feet 10 inches thick that contains 9.12 per cent of K_2O.

The showings of carnallite in the 17th Government test were the best of all in that series, but some of the private core tests also gave very good showings. In the 18th Government core test hole, in Loving County, Texas, a 1-foot 6-inch bed at a depth of 1441 feet contained carnallite with some sylvite and yielded 13.35 per cent of K_2O. The 12th test, also in Loving County, showed carnallite scattered in small amounts through a total range of 553 feet. At a depth of 1355 feet there was a 15-inch bed containing polyhalite, carnallite, and sylvite that yielded 8.65 per cent of K_2O. In shaft 1 of the United States Potash Co. at a depth of about 761 feet there is a 5½-foot bed of carnallite containing the equivalent of about 15 per cent of K_2O.

Possible use.—The showings of carnallite thus far obtained do not justify hope of commercial development in the face of the much richer deposits of sylvite. The carnallite may, however, find local use. The United States Potash Co., for example, has mined some for use in drilling solutions. Cores of potash-bearing salts obtained with the use of this material have been much more satisfactory than those obtained with types of solutions earlier used.

OTHER POTASH MINERALS AND ASSOCIATES

Kainite.—Kainite,[47] $KCl.MgSO_4.3H_2O$, has been observed in several of the cores, both public and private. It is massive, with a poorly developed fibrous fracture surface, and has a characteristic honey-yellow color with a rather dull or greasy luster. Its relations to other minerals in the cores strongly suggest that it is of secondary origin. As thus far recognized its small quantity and relatively low potash content preclude its having any commercial importance.

Kieserite.—Kieserite, $MgSO_4.H_2O$, though not itself potash-bearing, is closely associated with nearly all the saline minerals, chiefly with polyhalite, anhydrite, and halite, and thus deserves mention. It appears in many of the cores but nowhere in any quantity. It is pure white, has a vitreous luster, and forms compact granular fine-grained masses, the individual crystals of which are very small and generally rounded. Locally it has been replaced by leonite and polyhalite, but in most of its occurrences definite evidence of its reactions with other minerals is lacking.

Leonite.—Leonite, $K_2O.MgO.2SO_4.4H_2O$, has been identified in cores from the 17th Government test and several private tests. Its total quantity is very small, because it forms only small masses, seams, and specks intimately mixed with other minerals. Its relations to these minerals strongly suggest that it is chiefly of secondary origin.

SALT-DOME POTASH

The only potash thus far recognized in salt domes in the United States is that found in the Markham salt dome, in Matagorda County, Texas (p. 655). At present it has only scientific interest. In Grand County, Utah, at the site of the Crescent-Eagle well, surficial deposits mask the underlying structure. In the Salt Valley area, farther to the southeast, however, there are several wells whose cuttings have yielded sylvite. Structural conditions in these wells suggest that the salt beds containing the sylvite have been squeezed upward in a manner analogous to that observed in some parts of the German potash field.

[47]Schaller, W. T., and Henderson, E. P., *op. cit.*, pp 38–40, 44–46.

POTASH LAKES

In some of the western counties of Texas, notably Gaines, Lynn, Terry, Hockley, Lamb, Bailey, and Cochran counties, there are numerous "alkali lakes," or broad, flat depressions, usually occupied by encrustations of salts but occasionally flooded with a few inches of water. These vary in extent from about 35 to 7000 acres. The sands that form the bottoms of the lakes are impregnated to a depth of 5 to 20 feet or more with brine that is composed essentially of the sulphates and chlorides of sodium, magnesium, and potassium. Some of the brine also contains notable percentages of bromine.

During the World War and for a short period immediately thereafter these lakes became objects of interest as possible sources of potash. Private companies explored them in some detail, and the results of their explorations were made available to the Texas Bureau of Economic Geology and were included by that organization in one of its publications.[48] About the same time the Texas Bureau and the United States Geological Survey made an independent coöperative study of these lakes, and the general results of this investigation were released in a press notice.[49] The two reports cited deal with two different groups of these lakes, but the general nature of the brines in the two groups is similar. The conclusions reached in the joint investigation just mentioned follow:

> The feasibility of producing potash and bromine from these brines at a cost that will permit competition with potash and bromine produced from other sources depends on many factors, including the quantity of available brine in the region and the development of an economical process of extraction, and cannot be foretold. The location is unfavorable for obtaining fuel and labor and is far from markets, and as the brines occur in muds that lie beneath the surface, their production in quantity would be expensive and difficult.
>
> The salts of these brines contain a smaller percentage of potash (K_2O) than that yielded by the potash material of Germany, Alsace, Nebraska, and Searles Lake, but on the other hand they contain a relatively high percentage of bromine, which is comparatively scarce and is now produced in this country principally from salt and calcium chloride brines in Michigan, Ohio, and West Virginia. Much of the sodium sulphate of some of the brines of the region can probably be removed by refrigeration, which will leave in solution a product somewhat similar in composition to the German kainite. Such a probability indicates that a cheap process of obtaining the potash in marketable form might be devised.

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[48]Meigs, C. C., Bassett, H. P., and Slaughter, G. B., Report on Texas alkali lakes: Univ. Texas Bull. 2234, 60 pp., 1922.

[49]Potash and bromine in Texas lakes: U. S. Geol. Surv., Press Notice 441, April 12, 1920.

In the 15 years that have elapsed since these conclusions were printed, conditions in western Texas have changed: those affecting fuel and labor are better, but those affecting the demand for potash and bromine are less favorable. The oil industry has penetrated the region, and potash has been discovered in the salt beds of the Permian basin and is being mined in New Mexico. Additional sources of bromine have been found, including a commercially effective process for extraction of bromine from sea water.[50] A plant for this purpose has recently been constructed by the Ethyl Dow Chemical Co. at Kure Beach, about 20 miles south of Wilmington, North Carolina.[51] Thus the feasibility of producing potash and bromine from these lakes still appears remote.

NITRATE OF POTASH

Potassium nitrate, KNO_3, has been reported from many localities in central and western Texas, and attempts at exploitation of some of the deposits have been made at different times and places. None of these attempts have been successful.

The nitrate occurrences in Texas are chiefly of the "cave type," in which the material is found in caves, in recesses on canyon walls or cliffs, and in other places protected to a greater or less extent from the weather.

Cave deposits are surface or near-surface accumulations which may locally be highly pure. They form coatings on rock walls or fragments, fillings of crevices and cracks, and by falling down at the bases of cliffs they mingle with the earthy matter at such places. They do not penetrate more than a few inches or at most a few feet into the rock mass and then only along deep cracks or fissures.

Occurrences in Texas have been reported to the United States Geological Survey from Brewster, Culberson, Hudspeth, Lubbock, Presidio, Reeves, San Saba, and Val Verde counties. Many of these were visited 20 years or more ago by W. B. Phillips,[52] of the Texas Survey. His conclusions regarding them follow:

> From time to time during the last 10 years I have examined many localities in West Texas from which specimens of nitrate of soda and nitrate of potash were

[50]Stewart, L. C., Commercial extraction of bromine from sea water: Ind. and Eng. Chemistry, vol. 26, 361–369, April, 1934.

[51]Bromine from sea water: Eng. and Min. Jour., vol. 134, p. 403, 1933.

[52]Phillps, W. B., Investigations of sources of potash in Texas: Amer. Inst. Min. Eng., Bull. 98, pp. 124–126, 1915.

obtained, but I have yet to see a place which presents commercial possibilities of any moment whatsoever. I make this statement at this time to allay certain reports which have found some credence among those whose hopefulness has run away with their judgment. Rich specimens have been found at more than one locality, but in every case the situation has been such as to forbid any expectation of the finding of workable deposits.

The studies of the United States Geological Survey,[53] which were made at later intervals under representations from the War Department and from other sources, have served only to confirm the findings of Phillips.

ANALYSES AND DESCRIPTION OF CORES

This section of the paper comprises the results of mineralogic and chemical examinations made in the laboratory of the United States Geological Survey of portions of the core cut by W. B. Lang from the 23 Government potash test holes drilled in the Permian basin of Texas and New Mexico. The materials selected in the field for shipment to the Geological Survey laboratory in Washington were those portions having economic or scientific value. The remaining portions of core from the Salado halite, which were discarded, consisted essentially of halite, anhydrite, and shaly or sandy beds, more or less saliferous. The percentage of discard from the cores varied, ranging from 75 to 85 per cent. This material constitutes the "intervals" noted in the logs.

The laboratory reports have been corrected and compared with the field log by W. B. Lang, who has also reëxamined and checked by use of the petrographic microscope all of the economic core that facilities and time have permitted. For some cores important modifications have been made, and such cores are indicated in the heading to each list. Space does not permit enlarging the present scope of the reports, and the descriptions are left as nearly in the original form as the subsequent findings allow. All the reports have been revamped to conform to one style, and it is hoped that the rearrangement will prove a convenience to the reader.

[53]Mansfield, G. R., and Boardman, Leona, Nitrate deposits of the United States: U. S. Geol. Surv., Bull. 838, p. 52–95, 1932.

First Government Potash Test

Field notation: U. S. potash test, New Mexico No. 1.
Location: NE. ¼ sec. 13, T. 17 S., R. 31 E., Eddy County, N. Mex.
Elev. 3940 feet; top of salt 796 feet; T.D. 1847 feet.
Mineralogy by W. T. Schaller, E. P. Henderson, and F. C. Calkins.
Analyses by R. K. Bailey, J. G. Fairchild, E. T. Erickson, and J. J. Fahey.
Boron analyses: 17 samples tested about 0.1 per cent of B_2O_3; 79 samples tested less than 0.1 per cent of B_2O_3.
Remarks: Log corrected and revamped but core material not reëxamined. Some short sections from the upper portion of the log have been omitted as superfluous.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
758′10″–759′7″	9″	Gray anhydrite with minor inclusions of red halite and irregular thin magnesite seams. Less than 1.5% of K_2O.			- - -
		Interval of 62′5″.			
822′–822′3″	3″	Redbeds with halite and red spots of polyhalite. White areas in contact with polyhalite and halite are anhydrite, kieserite, and polyhalite.	36.00	1.25	3.47
		Interval of 16′.			
838′3″–838′9″	6″	Red polyhalite irregularly seamed with whitish anhydrite and gray-green shale. Drilling solution has leached the more soluble seams that were probably filled with carnallite, which is present deeper within the core.	58.80	5.79	9.85
		Interval of 5″.			
839′2″–839′4″	2″	Irregularly seamed anhydrite and polyhalite with thin seams of carnallite.	65.60	8.10	12.35
		Interval of 34′3″.			
873′7″–874′4″	9″	Polyhalite and anhydrite with small seams of halite and a scattering of kieserite.	70.50	7.05	10.10
874′4″–874′5″	1″	Halite with white granular anhydrite.	99.00	.75	.76
874′5″–875′2″	9″	Halite with anhydrite and a little red polyhalite with irregular bands of kieserite.	61.80	3.25	5.23

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
875′2″–875′3″	1″	Gray anhydrite with patches of dull red polyhalite.	49.80	2.75	5.52
875′3″–875′6″	3″	Gray anhydrite with spotty zones of red polyhalite.	50.70	5.02	9.89
875′6″–875′10″	4″	Gray anhydrite with thin bands of polyhalite.	33.50	1.85	5.52
875′10″–876′	2″	Halite with red blebs of polyhalite and thin seam of kieserite.	97.70	1.20	1.23
876′–876′2″	2″	Gray anhydrite with fine-grained polyhalite and seam of halite. Carnallite.	74.30	3.81	5.12
876′2″–876′7″	5″	Red polyhalite with enclosed crystals of anhydrite and an intergranular inclusion of carnallite. Kieserite.	67.40	10.67	17.35
		Interval of 7′9″.			
884′4″–884′6″	2″	Brownish-red clay containing halite and carnallite.	58.30	4.25	7.28
884′6″–884′9″	3″	Red clay with halite and carnallite.	56.40	2.02	3.59
		Interval of 8′9″.			
893′6″–893′9″	3″	Reddish anhydrite with a thick band of white anhydrite. A show of kieserite.	71.20	1.50	2.11
893′9″–893′10″	1″	Red carnallite and halite.	80.20	16.47	20.52
893′10″–894′1″	3″	Halite with seams of greenish clay.	95.40	.55	.58
		Interval of 11′3″.			
905′4″–905′8″	4″	Gray anhydrite with some intermixed polyhalite. Kieserite and halite present.	34.70	2.07	5.97
905′8″–906′3″	7″	Gray anhydrite with an intermixture of halite and polyhalite.	34.42	2.26	6.57
906′3″–906′10″	7″	White anhydrite with some red spots that contain carnallite and sylvite(?). Less than 1.5% of K_2O.	----	--------	-------
906′10″–907′	2″	Anhydrite with patches of white kieserite. Less than 1.5% of K_2O.	----	--------	--------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
907′–907′2″	2″	Gray anhydrite with seams of kieserite and specks of reddish halite. No potash minerals recognized.	42.86	.66	1.51
907′2″–907′4″	2″	Anhydrite with magnesitic seams, with interspersed kieserite and reddish spots of halite. Less than 1.5% of K_2O.	-------	-------	-------
907′4″–907′6″	2″	Soft fine-grained magnesite with seams of carnallite. Completely soluble in HCl.	25.80	2.72	10.54
907′6″–907′9″	3″	Magnesite and anhydrite with a plug of carnallite.	25.24	2.37	9.39
907′9″–908′11″	1′2″	Anhydrite. Less than 1.5% of K_2O.	-------	-------	-------
908′11″–909′4″	5″	Anhydrite with small seams of magnesite. White kieserite and reddish halite present. Carnallite.	33.80	1.69	5.00
909′4″–909′6″	2″	Gray anhydrite with horizontal seams of magnesite. Sylvite(?) and halite present in small cavities. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 23′.			
932′6″–932′9″	3″	Halite with red blebs of polyhalite and anhydrite. Carnallite.	96.40	.96	1.00
932′9″–932′10″	1″	Halite with small inclusions (bi-refracting mineral).	89.74	1.82	2.06
932′10″–933′	2″	Intergrowth of white polyhalite and anhydrite with red and white carnallite in two seams and halite.	81.90	2.21	2.70
933′–933′3″	3″	White carnallite.	-------	-------	-------
933′3″–933′5″	2″	Halite and gray anhydrite. Less than 1.5% of K_2O.	-------	-------	-------
933′5″–933′7″	2″	Lavender carnallite with included halite.	75.42	15.24	20.20
933′7″–933′10″	3″	Brownish-red clay with halite and carnallite.	82.66	2.29	2.77
933′10″–934′	2″	Halite and anhydrite with carnallite and kieserite.	64.60	4.25	6.58
		Interval of 5′9″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
939'9"–939'11"	2"	Halite with inclusions of anhydrite, carnallite, and kieserite. Polyhalite.	84.24	2.97	3.52
939'11"–940'	1"	Halite with inclusions of red polyhalite and anhydrite. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 7'7".			
947'7"–947'9"	2"	Halite.	98.70	.51	.52
947'9"–948'	3"	Carnallite with brown clay and included halite.	97.82	16.05	20.10
948'–948'3"	3"	Halite with brownish-red clay. Less than 1.5% of K_2O.	-------	-------	-------
948'3"–948'6"	3"	Halite with brownish-red clay.	92.26	.66	.72
		Interval of 35'10".			
984'4"–984'7"	3"	Carnallite with included halite.	79.50	15.95	20.06
984'7"–985'	5"	Carnallite with some halite.	74.42	11.77	15.83
985'–985'2"	2"	Brownish clay with small included masses of halite.	51.06	.83	1.62
		Interval of 10'5".			
995'7"–995'9"	2"	White anhydrite with red polyhalite and halite. Seams of green clay.	71.90	3.96	5.51
		Interval of 13'8".			
1009'5"–1009'6"	1"	Halite	98.60	1.05	1.06
1009'6"–1009'7"	1"	Anhydrite and polyhalite with some kieserite.	69.00	7.10	10.29
1009'7"–1009'10"	3"	White anhydrite containing fine-grained polyhalite. Small seams of brownish-red halite with inclusions of anhydrite. Sylvite.	58.10	7.38	12.70
		Interval of 10".			
1010'8"–1010'10"	2"	Anhydrite with red polyhalite and kieserite and seams of magnesite. Some halite.	58.30	2.17	3.72
		Interval of 7'10".			
1018'8"–1018'10"	2"	Anhydrite with white polyhalite. Specks of brownish-red sylvite and halite.	47.80	10.62	22.23

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1018′10″–1019′	2″	Anhydrite.	--------	--------	--------
1019′–1020′	1″	Anhydrite with small inclusions of sylvite, also kieserite and small spots of polyhalite.	60.70	2.46	4.05
		Interval of 9′6″.			
1029′6″–1030′	6″	Red polyhalite and anhydrite with green and brown clay and halite. Carnallite.	71.72	4.21	5.87
		Interval of 40′8″.			
1070′8″–1070′9″	1″	Halite with inclusions of polyhalite and anhydrite.	96.00	1.93	2.05
1070′9″–1071′4″	7″	Fine-grained polyhalite with seams of halite and inclusion of carnallite.	87.40	10.04	12.83
1071′4″–1071′7″	3″	Halite with seams of carnallite.	94.50	5.96	6.31
		Interval of 2′9″.			
1074′4″–1074′5″	1″	Halite and a little carnallite.	99.00	1.54	1.56
1074′5″–1074′10″	5″	Halite and anhydrite with brownish-red clay. Carnallite.	42.20	1.74	4.21
1074′10″–1075′	2″	Carnallite.	--------	--------	--------
		Interval of 10′.			
1085′–1085′10″	10″	Halite with bands of orange-colored polyhalite.	95.88	6.66	6.95
1085′10″–1086′	2″	Anhydrite and polyhalite.	--------	--------	--------
1086′–1086′2″	2″	Orange-colored polyhalite with colorless halite and pink carnallite.	71.38	11.62	16.28
1086′2″–1087′	10″	Orange-colored polyhalite and white anhydrite. Kieserite.	85.00	8.88	10.45
1087′–1087′1″	1″	Colorless halite with polyhalite inclusions.	98.60	1.35	1.37
		Interval of 11″.			
1088′–1088′6″	6″	Halite with a 1″ band of carnallite. Green and brown clay.	84.00	1.93	2.30
		Interval of 16′10″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1105′4″–1105′8″	4″	Orange-colored polyhalite with halite and seam of carnallite.	81.00	8.40	10.37
		Interval of 7′11″.			
1113′7″–1114′2″	7″	Halite with thin seams of carnallite. Mottled brown clay, kieserite, and carnallite.	86.60	3.47	4.01
		Interval of 2′3″.			
1116′5″–1116′8″	3″	Fine-grained polyhalite and anhydrite with kieserite.	65.60	7.34	11.19
		Interval of 60′4″.			
1177′–1177′9″	9″	Anhydrite with numerous small seams of polyhalite and magnesite cutting across core.	67.40	2.99	4.96
		Interval of 98′2″.			
1186′11″–1187′1″	2″	Large light-colored waxy-textured masses of polyhalite, surrounded by anhydrite. Irregular areas of carnallite.	65.00	4.44	6.83
		Interval of 14′5″.			
1201′6″–1201′8″	2″	Halite with red polyhalite.	99.80	2.70	2.71
1201′8″–1202′9″	1′2″	Red polyhalite with kieserite and halite. Seam of green clay.	70.40	9.94	14.22
1202′9″–1202′10″	1″	Green clay with masses of brown polyhalite. Carnallite.	35.20	1.93	5.48
		Interval of 4′4″.			
1207′2″–1207′4″	2″	Halite with red polyhalite.	97.80	3.47	3.55
1207′4″–1207′7″	3″	Halite with seams of brownish-red clay. Specks of polyhalite. Less than 1.5% of K_2O.	--------	-- - --	-- ----
		Interval of 8′.			
1215′7″–1215′8″	1″	Coarse crystalline halite with red polyhalite.	98.80	2.12	2.16
1215′8″–1215′10″	2″	Halite containing inclusions of polyhalite and carnallite.	99.40	1.25	1.26
1215′10″–1216′2″	4″	Halite with a ½-inch seam of waxy-textured white and red polyhalite.	99.20	2.12	2.14

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1216′2″–1216′4″	2″	Halite with inclusions of anhydrite and polyhalite. Less than 1.5% of K_2O.	-------	-------	-------
1216′4″–1216′6″	2″	Halite with inclusions of polyhalite. Less than 1.5% of K_2O.	-------	-------	-------
1216′6″–1216′9″	3″	Halite with large irregular masses of dull-white waxy polyhalite.	98.40	.70	.71
1216′9″–1217′	3″	Halite with irregular seams of dull-white waxy polyhalite and a little carnallite and kieserite.	97.40	5.75	6.92
1217′–1217′2″	2″	Dull-white waxy polyhalite with some halite.	73.80	11.10	15.03
1217′2″–1217′5″	3″	Dull-white waxy polyhalite with irregular masses of halite.	77.70	10.18	13.10
1217′5″–1217′7″	2″	Dull-white waxy polyhalite in between masses of halite.	82.20	10.67	12.98
1217′7″–1217′9″	2″	Dull-white waxy polyhalite with halite and carnallite.	77.40	11.15	14.34
		Interval of 20′.			
1237′9″–1238′	3″	Halite with seams of brownish-red clay. Specks of red polyhalite in the halite. Seam of green clay.	85.00	.85	1.00
1238′–1238′4″	4″	Granular halite with brownish-red clay. Specks of polyhalite. Less than 1.5% of K_2O.	-------	-------	-------
1238′4″–1238′8″	4″	Halite with brownish-red clay and a seam of green clay. Less than 1.5% of K_2O.	-------	-------	-------
1238′8″–1239′1″	5″	Brownish-red clay and halite. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 1″.			
1239′2″–1239′6″	4″	Halite with small inclusions of polyhalite and a seam of carnallite.	89.60	2.07	2.31
		Interval of 10′6″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1250′-1250′3″	3″	Halite with inclusions of red polyhalite.	98.70	.90	.91
1250′3″-1250′6″	3″	Halite with inclusions of polyhalite and kieserite.	96.90	2.94	3.03
1250′6″-1250′8″	2″	Halite containing inclusions of polyhalite and carnallite.	97.80	1.80	1.84
1250′8″-1250′11″	3″	Halite with seam of green clay and small mass of carnallite.	95.90	.65	.68
1250′11″-1251′	1″	Halite with spots of polyhalite.	98.90	.75	.76
1251′-1251′2″	2″	Halite with an inclusion of carnallite. Less than 1.5% of K_2O.	-------	--- --	--- ----
1251′2″-1251′6″	4″	Halite with an inclusion of carnallite.	93.80	2.48	2.64
1251′6″-1251′7″	1″	Coarse granular halite with carnallite between cubical masses of halite.	93.00	4.58	4.93
1251′7″-1251′10″	3″	Halite and red carnallite.	89.60	6.85	7.63
1251′10″-1251′11″	1″	Carnallite with included halite.	84.50	11.50	13.61
1251′11″-1252′	1″	Halite with inclusions of polyhalite.	94.90	3.81	4.02
1252′-1252′1″	1″	Halite with inclusion of polyhalite.	97.80	1.55	1.58
1252′1″-1252′5″	4″	Halite and carnallite.	96.30	3.86	4.00
1252′5″-1252′10″	5″	Coarse crystalline halite with spots of carnallite.	98.40	1.43	1.45
1252′10″-1252′11″	1″	Halite with brownish-red clay.	99.72	1.11	1.11
1252′11″-1253′7″	8″	Halite with thin seam of carnallite.	98.26	1.44	1.46
1253′7″-1253′8″	1″	Shattered core consisting of halite and carnallite.	96.80	2.50	2.58
1253′8″-1253′9″	1″	Halite with brownish-red clay.	87.24	1.97	2.26
1253′9″-1254′	3″	Halite with seam of carnallite. Small green clay seams throughout core.	91.70	1.36	1.48
1254′-1254′2″	2″	Halite with a seam of green clay and irregular carnallite masses of variable size.	87.82	2.58	2.94

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1254′2″–1254′3″	1″	Halite and carnallite with green clay.	86.66	6.81	7.98
1254′3″–1254′5″	2″	Halite with carnallite inclusions.	91.80	2.01	2.19
1254′5″–1254′7″	2″	Halite, carnallite, and green clay.	78.84	2.83	3.59
1254′7″–1254′10″	3″	Halite with seams of carnallite and thin seams of green clay.	90.90	3.29	3.62
1254′10″–1255′	2″	Halite and carnallite.	93.22	2.11	2.26
1255′–1255′3″	3″	Halite and small inclusions of carnallite and polyhalite.	93.06	1.47	1.59
1255′3″–1255′4″	1″	Halite with masses of green clay and fine-grained inclusions of carnallite.	83.60	1.70	2.03
1255′4″–1255′8″	4″	Halite with green clay and small inclusions of polyhalite and carnallite.	74.04	1.05	1.42
1255′8″–1255′9″	1″	Carnallite and halite.	71.50	13.54	18.93
1255′9″–1256′	3″	Carnallite with inclusions of halite.	64.22	15.16	23.62
1256′–1256′2″	2″	Brownish-red clay and halite.	52.26	1.30	2.50
		Interval of 21′10″.			
1278′–1278′6″	6″	Colorless halite with inclusions of red polyhalite.	98.00	2.49	2.54
1278′6″–1279′	6″	Chiefly red polyhalite with halite inclusions.	69.24	10.99	15.86
1279′–1279′8″	8″	Dull-white fine-grained anhydrite with seams of red polyhalite cutting across core. Inclusions of halite in anhydrite.	38.60	1.45	3.76
1279′8″–1280′3″	7″	Gray anhydrite having a speckled appearance, with two red minerals, carnallite and polyhalite.	52.00	6.56	12.61
		Interval of 3″.			
1280′6″–1281′2″	8″	Gray anhydrite with small inclusions of red carnallite. Anhydrite gives the appearance of replacing halite.	48.20	1.74	3.61
		Interval of 1′.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1282′2″–1282′9″	7″	Gray anhydrite with irregular veins and inclusions of red polyhalite.	37.40	3.76	10.05
		Interval of 5′4″.			
1288′1″–1288′2″	1″	Shattered core; recovered material consists of fine grains of carnallite.	69.20	14.48	20.92
		Interval of 3′6″.			
1291′8″–1291′10″	2″	Shattered core; recovered material consists of dull reddish-brown polyhalite and green clay.	28.60	4.44	15.52
		Interval of 4′9″.			
1296′7″–1296′8″	1″	Halite with thin seam of red polyhalite.	99.60	2.22	2.23
		Interval of 2″.			
1296′10″–1297′	2″	Red polyhalite with small inclusions of halite.	81.20	13.03	16.06
1297′–1297′5″	5″	Dull-red polyhalite; two different shades of red. Small irregular inclusions of halite.	74.60	14.28	21.21
		Interval of 28′4″.			
1325′9″–1327′1″	1′4″	Halite with inclusions of red polyhalite in sharp contact with a 7″ seam of red polyhalite.	80.60	8.78	10.90
1327′1″–1327′2″	1″	Halite with small inclusion of some red material, probably polyhalite.	98.40	1.64	1.67
		Interval of 1′4″.			
1328′6″–1328′11″	5″	Granular halite with inclusions of red polyhalite.	97.00	1.83	1.89
		Interval of 29′.			
1357′11″–1358′6″	7″	Halite with masses of snowy-white kieserite. Few red inclusions of polyhalite.	96.00	.87	.90
		Interval of 4′10″.			
1363′4″–1363′11″	7″	Salmon-colored polyhalite with inclusions of halite and some polyhalite.	72.40	13.22	20.39

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1363′11″–1364′1″	2″	Halite with a seam of green clay which contains salmon-colored polyhalite.	81.40	2.70	3.32
		Interval of 8′1″.			
1372′2″–1372′9″	7″	Granular halite with green clay which contains some polyhalite. Most of core consists of thin seams of polyhalite, anhydrite, and magnesite.	84.60	3.57	4.22
1372′9″–1372′11″	2″	Grayish-white magnesite with small masses of polyhalite. Less than 1.5% of K_2O.	------	------	------
1372′11″–1373′2″	3″	Salmon-colored polyhalite with halite and anhydrite. Less than 1.5% of K_2O.	------	------	------
1373′2″–1373′4″	2″	Dark-red polyhalite with a little halite. Less than 1.5% of K_2O.	------	------	------
1373′4″–1373′7″	3″	Halite and anhydrite. Less than 1.5% of K_2O.	------	------	------
1373′7″–1374′	5″	Dull-red polyhalite with thin seam of halite.	69.20	14.10	20.30
1374′–1374′4″	4″	Halite with brownish-red and green clay.	55.80	1.45	2.59
		Interval of 4′10″.			
1379′2″–1379′8″	6″	Red polyhalite with inclusions of halite.	80.00	11.50	14.39
1379′8″–1379′11″	3″	Halite with small inclusions of salmon-colored polyhalite.	99.70	2.06	2.07
		Interval of 39′7″.			
1419′6″–1419′7″	1″	Halite with salmon-colored polyhalite and green clay.	95.02	2.26	2.38
1419′7″–1419′9″	2″	Halite with salmon-colored polyhalite and green clay.	98.74	1.59	1.61
1419′9″–1419′11″	2″	Halite with irregular inclusions of salmon-colored polyhalite.	77.30	7.05	9.13
1419′11″–1420′4″	5″	Halite and salmon-colored polyhalite.	89.54	2.33	2.61

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1420′4″–1421′4″	1′	Dull reddish-brown polyhalite.	77.60	12.25	15.80
1421′4″–1421′6″	2″	Halite with small amount of salmon-colored polyhalite and green clay. Less than 1.5% K_2O.	-----	-----	-----
		Interval of 57′1″.			
1478′7″–1478′9″	2″	Halite with inclusions of salmon-colored polyhalite.	98.26	2.68	2.73
1478′9″–1478′10″	1″	Halite and dull-red polyhalite.	90.90	8.31	9.15
1478′10″–1479′	2″	Dull-red polyhalite with gray anhydrite.	60.64	14.30	23.60
1479′–1479′9″	9″	Reddish polyhalite with included halite.	70.50	13.50	19.15
1479′9″–1480′	3″	Half of core is red polyhalite with a little halite; the remainder halite with some anhydrite.	96.20	6.17	6.41
		Interval of 16′8″.			
1496′8″–1497′2″	6″	Large irregular area of polyhalite; remainder of core is halite with small seams of polyhalite.	96.46	6.85	7.11
1497′2″–1497′8″	6″	Halite with large irregular masses of polyhalite.	96.80	6.90	7.13
		Interval of 45′1″.			
1542′9″–1542′11″	3″	Halite with a band of polyhalite.	92.80	5.12	5.52
		Interval of 7′1″.			
1550′–1550′2″	2″	Rounded masses of reddish polyhalite surrounded with anhydrite. Some halite present.	55.70	3.86	6.93
1550′2″–1550′6″	4″	Salmon-colored polyhalite with brownish-red clay and halite.	70.20	10.58	15.05
		Interval of 16′3″.			
1566′9″–1566′11″	2″	Halite with polyhalite inclusions.	98.90	2.46	2.49
1566′11″–1567′1″	2″	Seam of halite in contact with polyhalite that contains small inclusion of halite.	96.66	8.11	8.40

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1567′1″–1567′6″	5″	Dull-red polyhalite with thin broken seams of halite.	67.80	13.52	20.00
1567′6″–1567′8″	2″	Halite. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 7′.			
1574′8″–1575′	4″	Halite with inclusion of polyhalite.	99.00	3.47	3.50
1575′–1575′2″	2″	Halite with a thick seam of polyhalite, which is in sharp contact with the following sample.	98.60	5.14	5.21
1575′2″–1575′5″	3″	Anhydrite and magnesite. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 18′2″.			
1593′7″–1594′4″	9″	Polyhalite containing halite, anhydrite, and thin seam of magnesite and anhydrite.	82.20	6.85	8.34
1594′4″–1594′8″	4″	Anhydrite and magnesite with thin seams of polyhalite. Some halite.	62.40	1.35	2.16
		Interval of 9′11″.			
1604′7″–1604′10″	3″	Polyhalite with halite and a little green clay.	74.40	8.20	11.02
		Interval of 15′2″.			
1620′–1620′7″	7″	Halite with polyhalite inclusions.	98.80	1.64	1.66
1620′7″–1620′10″	3″	Anhydrite with thin magnesite seams at base. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 25′9″.			
1646′7″–1647′	5″	Anhydrite with salmon-colored polyhalite irregularly distributed throughout. Some fine-grained material, probably magnesite.	59.40	6.18	10.40
1647′–1648′4″	1′4″	Core has a mottled appearance showing irregular and broken seams of red polyhalite and dull white magnesite with irregular masses of anhydrite. Spherulites of polyhalite were noticed throughout this core.	62.20	8.59	13.81

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1648′4″–1651′5″	3′1″	Appearance is the same as described above.	49.40	7.33	14.84
1651′5″–1652′	7″	Anhydrite with irregular seams of magnesite running across the core. Anhydrite contains a little polyhalite.	28.20	.68	2.41
		Interval of 7′4″.			
1659′4″–1659′8″	4″	Dull-red polyhalite with a little halite.	78.80	14.00	17.77
1659′8″–1659′9″	1″	Brown clay showing an indistinct contact with polyhalite and halite.	59.40	6.66	11.29
		Interval of 30′4″.			
1690′1″–1690′5″	4″	Halite with included masses of polyhalite.	98.60	2.32	2.35
1690′5″–1690′8″	3″	Dull-red polyhalite with coarse halite included.	67.20	14.67	21.84
1690′8″–1690′11″	3″	Halite with salmon-colored polyhalite and green clay.	72.80	4.34	5.98
		Interval of 37′4″.			
1728′3″–1728′5″	2″	Halite with inclusions of polyhalite.	99.40	1.83	1.84
1728′5″–1728′10″	5″	Halite with included polyhalite.	98.40	5.80	5.90
		Interval of 39′1″.			
1767′11″–1768′2″	3″	Halite with polyhalite inclusions.	96.80	1.64	1.69
1768′2″–1768′9″	7″	Halite with small irregular seams of polyhalite. Less than 1.5% of K_2O.	- -	- - - -	- - - -
1768′9″–1769′4″	7″	Halite and included polyhalite.	97.40	1.88	1.93
1769′4″–1769′9″	5″	Halite with fine-grained polyhalite disseminated throughout. Some halite is free from this inclusion.	98.90	2.60	2.63
1769′9″–1770′10″	1′1″	Halite with included polyhalite.	95.30	4.96	5.71
		Interval of 17′6″.			
1788′4″–1789′2″	10″	Halite with inclusions of polyhalite.	99.10	1.00	1.01
		Interval of 41′10″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1831′–1831′3″	3″	Halite with inclusions of dull-red clay. Less than 1.5% of K_2O.	------	--------	--------
1831′3″–1831′6″	3″	Anhydrite containing a little polyhalite. Some halite in seams.	62.10	.45	.72
1831′6″–1831′7″	1″	Dull brownish-red clay. Less than 1.5% of K_2O.	------	--------	--------
		Interval of 3′10″.			
1835′5″–1835′8″	3″	Anhydrite with a fine-grained inclusion in the seams, possibly magnesite. Considerable brownish-red clay with some halite in this core.	42.70	.50	1.17
1835′8″–1836′	4″	Halite with irregular masses of brownish-red clay. Less than 1.5% of K_2O.	------	--------	--------
		Interval of 1″.			

Second Government Potash Test

Field notation: U. S. potash test, New Mexico No. 2.
Location: NE. ¼ NE. ¼ sec. 14. T. 20 N., R. 29 E., Eddy County, N. Mex.
Elev. 3315 feet; top of salt 335 feet; T.D. 1101 feet.
Mineralogy by E. P. Henderson.
Analyses by R. K. Bailey, E. T. Erickson, and J. J. Fahey.
Boron analyses: 5 samples tested about 0.1 per cent of B_2O_3; 85 samples tested less than 0.1 per cent of B_2O_3.
Remarks: Log corrected but core not reëxamined. This log records the results of the first drilling. The offset core, drilled from 240 to 411 feet, is essentially the same as the first, except where noted.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
349′–349′7″	7″	Halite with seams of polyhalite.	83.40	6.32	7.59
349′7″–350′	5″	Polyhalite with small quantity of halite.	73.40	11.92	16.27
		Interval of 18′10″.			
368′10″–369′10″	1′	Halite with small seams and blebs of polyhalite. Less than 1.5% of K_2O.	-------	--------	--------
369′10″–371′6″	1′8″	Polyhalite containing some halite and anhydrite. (Carnallite in offset core.)	75.10	11.53	15.35
		Interval of 13′8″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
385′2″–385′8″	6″	Halite with seams of green clay. Small blebs of polyhalite. Less than 1.5% of K_2O.	———	———	———
		Interval of 9″.			
386′5″–387′2″	9″	White halite with red inclusions of polyhalite. A 1″ layer of polyhalite. Less than 1.5% of K_2O.	———	———	———
		Interval of 5′1″.			
392′3″–394′	1′9″	Granular halite with red sylvite. Considerable brownish and green clays scattered throughout.	83.40	3.19	3.83
		Interval of 23′2″.			
417′2″–417′6″	4″	Halite. Less than 1.5% of K_2O.	———	———	———
417′6″–420′	2′6″	Blebs of polyhalite and kieserite in halite. Several small layers of polyhalite in the halite.	85.80	4.25	4.93
		Interval of 17′8″.			
437′8″–439′3″	1′7″	Halite with blebs of polyhalite and clay. Less than 1.5% of K_2O.			
		Interval of 7″.			
439′10″–441′	1′2″	Halite containing small blebs of a red mineral (carnallite and polyhalite). Greenish clay fills many of the cracks in the halite. Less than 1.5% of K_2O.	———	———	———
		Interval of 4′5″.			
445′5″–447′8″	2′3″	Granular halite with blebs of a red mineral, chiefly red halite. Small pieces of carnallite were noticed. Considerable green clay. Less than 1.5% of K_2O.	———	———	———
		Interval of 5′.			
451′8″–452′5″	9″	Halite with blebs of red polyhalite. Less than 1.5% of K_2O. A 1″ layer of polyhalite and halite.	———	———	———
		Interval of 4′11″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
457′4″–458′9″	1′5″	Granular halite and greenish clay. Layer of brownish-red clay. Less than 1.5% of K_2O.	----	----	----
		Interval of 3′1″.			
461′10″–462′4″	6″	Granular halite with small irregular seams of polyhalite. Less than 1.5% of K_2O.	----	----	----
		Interval of 7′8″.			
470′–472′	2′	Halite. From 470′2″ to 470′4″ a layer of granular halite, also from 470′9″ to 470′11″. Less than 1.5% of K_2O.	----	----	----
		Interval of 3′6″.			
475′6″–475′9″	3″	A 3″ layer of granular halite containing a seam of white polyhalite. Less than 1.5% of K_2O.	----	----	----
475′9″–477′	1′3″	White polyhalite with irregular patches of halite.	78.10	12.00	15.35
		Interval of 8′2″.			
485′2″–485′6″	4″	Granular halite showing a rather sharp contact with the following sample. Less than 1.5% of K_2O.	----	----	----
485′6″–487′4″	1′10″	Polyhalite with some anhydrite and kieserite.	64.40	12.20	18.95
487′4″–488′2″	10″	Anhydrite containing polyhalite and halite.	49.90	6.75	13.53
		Interval of 1′10″.			
490′–490′9″	9″	Anhydrite, magnesite, and some dark-gray clay. Halite in seams.	38.10	3.28	8.60
490′9″–492′	1′3″	Halite with blebs of polyhalite making a sharp contact with the previous sample. Polyhalite is apparently concentrated just below contact in the halite. Some polyhalite scattered throughout. Less than 1.5% of K_2O.	----	----	----
		Interval of 10′.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
502′–505′	3′	Halite with blebs of red sylvite. Small inclusions of kainite and anhydrite.	96.20	7.19	7.47
		Interval of 6′4″.			
511′4″–515′3″	3′11″	Blebby halite containing red inclusions of sylvite and polyhalite. Also some brownish-red clay. Some greenish clay is present.	93.30	6.17	6.62
		Interval of 2′6″.			
517′6″–517′10″	4″	Halite with small seams of polyhalite.	98.40	2.51	2.55
517′10″–518′8″	10″	Polyhalite with halite and green clay.	74.30	13.09	17.60
518′8″–519′1″	5″	Granular halite.	96.80	1.80	1.86
		Interval of 19′3″.			
538′4″–538′7″	3″	Halite with inclusions of brown and greenish clay. Less than 1.5% of K_2O.	....	....	....
538′7″–539′6″	11″	Polyhalite with small halite lenses.	69.50	12.20	17.55
539′6″–540′	6″	Green clay making a sharp contact with above-described polyhalite, followed by granular halite with green clay inclusions.	96.40	2.85	2.96
		Interval of 10′8″.			
550′8″–551′9″	1′1″	Halite with irregular seams of polyhalite. Less than 1.5% of K_2O.	....	....	....
		Interval of 4′4″.			
556′1″–556′7″	6″	Halite with irregular seams of polyhalite. Less than 1.5% of K_2O.	....	....	....
		Interval of 2′2″.			
558′9″–561′3″	2′6″	Halite with irregular seams of polyhalite. A 2″ layer of polyhalite at 559′2″.	78.70	1.80	2.29
		Interval of 6′6″.			
567′9″–569′6″	1′9″	White halite with blebs of polyhalite. A 10″ layer of polyhalite and anhydrite making a sharp contact with halite.	91.00	3.28	3.60
		Interval of 12′6″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
582′–584′10″	2′10″	Granular halite with blebs of polyhalite. Some brown clay present.	96.30	2.02	2.10
584′10″–586′2″	1′4″	Polyhalite with some halite and anhydrite.	58.90	8.44	14.32
586′2″–587′1″	11″	Sandy clay, grains consisting chiefly of quartz. Some halite is present, and a few blebs of polyhalite. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 4′1″.			
591′2″–591′11″	9″	Halite with thin irregular seams of polyhalite.	98.4	1.54	1.57
591′11″–592′8″	9″	Polyhalite with small blebs of halite followed by 5″ layer of solid polyhalite.	70.90	13.08	14.32
592′8″–593′1″	5″	Granular halite with small seams of polyhalite and green clay. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 43′8″.			
635′–635′10″	10″	Halite with irregular seams of polyhalite. Polyhalite is rather needle-like in crystal habit and resembles anhydrite. A 2″ layer of green clay is followed by granular halite; both clay and halite contain some polyhalite.	75.90	3.76	4.96
		Interval of 21′6″.			
657′4″–657′7″	3″	Halite with polyhalite inclusions. Less than 1.5% of K_2O.	-------	-------	-------
657′7″–659′	1′5″	1″ of polyhalite containing small amount of halite and anhydrite. This makes a sharp contact with about 4″ of banded anhydrite and magnesite, which contains thin layers of polyhalite.	56.80	7.30	12.85
659′–662′9″	3′9″	A layer of dark-colored clay followed by granular halite containing blebs of polyhalite. A 4″ layer of polyhalite with	-------	-------	-------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		a seam of halite at 660′ 10″. Less than 1.5% of K_2O.			
		Interval of 1′10″.			
664′7″–665′	5″	Halite with seams of polyhalite. Less than 1.5% of K_2O.	-------	-------	-----
		Interval of 10′8″.			
675′8″–679′3″	3′7″	Halite with irregular seams of polyhalite. Several seams of green clay.	97.80	1.90	1.94
679′3″–682′5″	3′2″	Large blebs of polyhalite and anhydrite. Poorly defined seams of halite. At 681′ a layer of halite with wedges of anhydrite at 681′3″ to 682′5″. The anhydrite contains white polyhalite, also blebs of red polyhalite.	60.40	4.97	8.23
682′5″–683′8″	1′3″	Thin layer of blebby halite, the blebs being polyhalite and anhydrite. Anhydrite mixed with ill-defined seams of magnesite making contact with blebs of polyhalite. Less than 1.5% of K_2O.	-----	------	-----
		Interval of 26′9″.			
710′5″–711′11″	1′6″	Halite with irregular seams and blebs of polyhalite. Considerable anhydrite in the polyhalite masses. At 711′ a thin layer of brownish-red clay followed by granular halite with inclusions of green clay. Less than 1.5% of K_2O.	--------	------	------
		Interval of 18′8″.			
730′7″–730′11″	4″	Granular halite with small inclusions of a pink mineral, probably polyhalite. Less than 1.5% of K_2O.	-----	------	------
730′11″–733′2″	2′3″	Granular halite with blebs of polyhalite grading into polyhalite. 1′7″ consists of polyhalite with	75.20	9.40	12.50

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		small seams of anhydrite. At 733′2″ a thin layer of clay and magnesite.			
		Interval of 1″.			
733′3″–733′5″	2″	Halite with a few inclusions of polyhalite. Thin seams of green clay. Less than 1.5% of K_2O.	--------	--------	------
		Interval of 13′3″.			
746′8″–748′6″	1′10″	Halite with angular blebs of polyhalite. Elongated anhydrite crystals cutting some of the polyhalite. From 748′ to 748′6″ halite with only a few small polyhalite blebs. Less than 1.5% of K_2O.	------	--------	------
		Interval of 3′5″.			
751′11″–752′6″	7″	Core shattered in drilling. Consists of broken pieces of red polyhalite and halite.	94.00	4.15	4.42
		Interval of 34′9″.			
787′3″–787′10″	7″	Halite with a few large blebs of polyhalite. Less than 1.5% of K_2O.	-------	-------	------
		Interval of 8′10″.			
796′8″–797′1″	5″	Halite with irregular seams of polyhalite. Less than 1.5% of K_2O.	-------	--------	--------
		Interval of 2′11″.			
800′–801′	1′	Halite and blebs of polyhalite with an indefinite layer of polyhalite containing anhydrite grading into anhydrite, magnesite, and greenish clay. Less than 1.5% of K_2O.	-------	--------	--------
801′–801′4″	4″	Granular halite with blebs of polyhalite. Some green clay. Less than 1.5% of K_2O.	--------	-------	--------
		Interval of 6′3″.			
807′7″–809′7″	2′	Granular halite in contact with a mixture of anhydrite and magnesite. The	--------	- -	------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		halite has the appearance of replacing anhydrite. From 808′6″ to 809′7″ the core is blebby anhydrite with halite forming the blebs. A great number of 6-sided halite masses occur in the anhydrite. A small piece of red clay containing gypsum crystals was included in this core section at 809′2″. [Undoubtedly an accidental inclusion—W. B. L.] Less than 1.5% of K_2O.			
809′7″–812′	2′5″	Polyhalite with a few inclusions of halite.	65.60	13.94	21.25
812′–812′10″	10″	Light-green clay with magnesite. Small indefinite seams of polyhalite and some halite.	85.00	1.64	1.93
		Interval of 12′5″.			
825′1″–825′3″	2″	Anhydrite with magnesite. Some halite and a little brownish clay. Less than 1.5% of K_2O.	------	------	------
		Interval of 26′10″.			
852′1″–852′8″	7″	Thin layer of light-colored clay followed by granular halite. Less than 1.5% of K_2O.	------	------	------
852′8″–854′2″	1′6″	Halite with seams of polyhalite grading into polyhalite. Thin irregular seams of anhydrite. At 845′2″ a thin layer of clay and magnesite.	87.40	8.64	9.88
854′2″–854′11″	9″	Granular halite with greenish clay inclusions. Less than 1.5% of K_2O.	------	------	------
		Interval of 2′11″.			
857′10″–858′7″	9″	Halite with blebs of polyhalite.	98.00	2.80	2.86
		Interval of 7′2″.			
865′9″–867′8″	1′11″	Halite with blebs of polyhalite passing into halite and anhydrite. Less than 1.5% of K_2O.	------	------	------
		Interval of 21′2″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
888′10″–890′9″	1′11″	Fine-grained anhydrite with blebby seams of halite. Good contact of anhydrite and polyhalite. Less than 1.5% of K_2O.	--------	--------	--- ----
890′9″–891′8″	11″	Polyhalite with some anhydrite and halite.	62.90	11.40	18.15
891′8″–892′7″	11″	Anhydrite containing small inclusion of polyhalite grading into clay and magnesite; clay layer is followed by granular halite. Less than 1.5% of K_2O.	-------	-------	--- ----
		Interval of 53′5″.			
946′–947′	1′	Anhydrite with some halite. Less than 1.5% of K_2O.	-- - -	-- -----	-------

Third Government Potash Test

Field notation: U. S. potash test, New Mexico No. 3.
Location: SW. ¼ SW. ¼ sec. 34, T. 22 S., R. 30 E., Eddy County, N. Mex.
Elev. 3152 feet; top of salt 365 feet (approx.); T.D. 1501 feet.
Mineralogy by E. P. Henderson.
Analyses by R. K. Bailey and E. T. Erickson.
Boron analyses: 2 samples tested about 0.07 per cent of B_2O_3; 41 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 43 samples tested less than 0.05 per cent of Br.
Iodine analyses: 43 samples tested less than 0.05 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
365′10″–367′3″	1′5″	Brown clay containing halite followed by polyhalite, including small amount of halite. Seams in the polyhalite are lined with coarse crystalline polyhalite; seams also contain some halite. Some anhydrite toward lower end of core.	60.90	8.64	14.19
		Interval of 96′1″.			
463′4″–464′1″	9″	Polyhalite with thin seams of halite. Granular halite with small quantity of polyhalite.	89.20	9.22	10.33
		Interval of 7′11″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
472′–472′7″	7″	Halite with irregular seams of polyhalite. One seam about 2½″ of polyhalite.	86.40	9.65	11.17
		Interval of 169′7″.			
642′2″–643′5″	1′3″	Polyhalite with a thin seam of halite.	78.40	11.25	14.36
643′5″–644′4″	11″	Halite with very small quantity of polyhalite. One poorly defined seam of polyhalite with greenish clay, followed by bands of similar clay containing inclusions of polyhalite. Some cubic masses of halite associated with clay.	90.00	2.27	2.52
		Interval of 53′6″.			
679′10″–680′11″	1′1″	Halite with irregular seams of polyhalite. Small layer of halite and anhydrite.	93.30	3.86	4.13
680′11″–683′	2′1″	Anhydrite with irregular seams of halite. Some magnesite is contained in the anhydrite. Polyhalite with irregular blebs of magnesite; also thin layers of halite and anhydrite. Clay at the upper end of core.	63.20	8.25	13.05
		Interval of 12′.			
695′–696′	1′	Halite with masses of polyhalite for 5″ followed by polyhalite containing small masses of halite.	82.90	10.20	12.31
		Interval of 33′.			
729′–730′1″	1′1″	Anhydrite with halite to 729′9″, where a 1″ layer of polyhalite cuts across core. Remainder is anhydrite and halite.	52.30	1.64	3.13
730′1″–732′	1′11″	First 2″ of core polyhalite, halite, and anhydrite. From 730′3″ to 731′ core is chiefly polyhalite with some halite. From 731′ to 731′4″ a layer of halite with included polyhalite. From 731′4″ to	75.40	8.88	11.80

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		731′7″ a layer of polyhalite, and from 731′7″ to the end of the core is banded anhydrite, halite, and polyhalite.			
		Interval of 7′5″.			
739′5″–741′	1′7″	Polyhalite with thin layer of halite. From 740′8″ to 740′10″ a band of anhydrite containing a poorly defined seam of halite.	64.90	12.55	19.35
		Interval of 65′.			
806′–860′	54′	Core lost. Recovery of a few shattered fragments of core indicates presence of halite, anhydrite, polyhalite, and magnesite. Less than 1.5% of K_2O. No analysis made.	-	-	- -
		Interval of 7′8″.			
867′8″–868′1″		Halite with some polyhalite. Halite has appearance of being partly dissolved.	97.80	2.75	2.81
868′1″–871′3″	3′2″	An 8″ layer of polyhalite which contains irregular seams of halite. At 868′ 9″ a 1″ layer of polyhalite, halite, and greenish clay. Small quantity of clay is noticeable for short distance each side of this layer. At 871′ a thin seam of halite with some polyhalite. All the halite has the appearance of being partly dissolved.	66.80	13.50	20.20
		Interval of 14′1″.			
871′3″–910′	38′9″	Core lost. Fragmental recovery. Polyhalite, anhydrite, halite. No chemical determination.	-	---- - -	--- -
910′–911′	1′	Polyhalite, white and glassy in appearance; contains small inclusions of anhydrite. Remainder of core is polyhalite and anhydrite with a layer of green clay about 1″	49.30	7.76	15.75

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		thick. Some halite in the clay.			
		Interval of 5′10″.			
916′10″–918′	1′2″	First 2″ is largely halite with thin irregular bands of polyhalite. Halite appears to have been partly dissolved. Remainder of core is polyhalite with a thin seam of anhydrite and a 2″ layer of halite and polyhalite.	72.10	11.83	16.42
		Interval of 33′8″.			
951′8″–952′5″	9″	Polyhalite with disseminated anhydrite.	63.80	14.24	22.32
952′5″–952′9″	4″	Halite with some crystalline polyhalite.	96.00	5.21	5.43
952′9″–953′11″	1′2″	Center of the first 1″ or so of core has a large mass of halite surrounded by polyhalite. The halite appears to have been partly dissolved, and well-crystallized polyhalite now stands out in relief. Remainder of core is polyhalite, halite, and some disseminated clay.	66.10	14.68	22.18
		Interval of 56′8.″			
1010′7″–1012′3″	1′8″	Anhydrite with some halite. Small quantity of finely disseminated polyhalite throughout core. Quantity increases with depth.	62.10	3.18	5.12
1012′3″–1014′3″	2′	White polyhalite with small quantity of anhydrite and halite.	65.30	14.82	22.70
1014′3″–1015′10″	1′7″	White polyhalite which grades into anhydrite in the last 4″ of core.	53.10	10.38	19.52
		Interval of 19′5″.			
1035′3″–1036′3″	1′	First 1″ of core contains clay and some magnesite with a little polyhalite. Remaining 11″ is polyhalite.	63.40	13.90	21.93
		Interval of 25′9″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1062′–1062′4″	4″	Polyhalite with some halite disseminated throughout.	70.60	12.50	17.70
		Interval of 73′10″.			
1136′2″–1137′1″	11″	First 2″ of core is a mixture of halite and polyhalite; remainder is polyhalite.	85.20	9.75	11.43
		Interval of 31′8″.			
1168′8″–1169′4″	8″	Halite with polyhalite; the quantity of polyhalite increases with depth.	86.70	9.45	10.90
1169′4″–1169′10″	6″	Halite with considerable polyhalite. The center portion of this section is largely halite, with small disseminated areas of polyhalite.	95.90	7.10	7.42
1169′10″–1170′6″	8″	Polyhalite and finely disseminated halite. A 1″ layer of halite at end of core.	75.00	12.93	17.25
		Interval of 29′8″.			
1200′2″–1201′3″	1′1″	From 1200′2″ to 1200′6″ granular halite with a little fine-grained polyhalite. From 1200′6 to 1201′3″ core is largely polyhalite with some halite.	77.80	12.05	15.50
1201′3″–1202′6″	1′3″	Chiefly polyhalite with the exception of a 2″ layer at the deeper end, which consists of halite with some polyhalite.	72.60	13.60	18.70
		Interval of 84′1″.			
1286′7″–1287′3″	8″	Polyhalite with some halite. A little clay is present at the base of the section.	80.30	11.10	13.83
		Interval of 28′3″.			
1315′6″–1316′6″	1′	Polyhalite with small quantity of halite. Some magnesite at the base.	66.50	14.30	21.48
		Interval of 16′4″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1332′10″–1333′1″	3″	Halite with large blebs of polyhalite, grading into polyhalite. Less than 1.5% of K_2O.	--------	--------	--------
1333′1″–1333′7″	6″	Polyhalite.	67.00	14.95	22.30
1333′7″–1334′	5″	Halite with very small quantity of polyhalite. Less than 1.5% of K_2O.	--------	--------	--------
		Interval of 5″.			
1334′5″–1336′9″	1′4″	A 1″ layer of halite which is followed by 11″ of polyhalite. From 1335′5″ to 1336′9″ core is largely polyhalite, with green clay and also some halite.	66.80	13.60	20.35
		Interval of 27′6″.			
1364′3″–1364′11″	8″	First 4″ of core is anhydrite with some halite and a very small quantity of polyhalite; remainder is anhydrite with some finely divided polyhalite disseminated throughout, also small blebs of polyhalite.	35.20	3.14	8.92
1364′11″–1366′11″	1′8″	Anhydrite with blebs of polyhalite grading into 18″ of polyhalite containing small quantity of halite.	57.70	10.97	19.00
		Interval of 15′10″.			
1382′5″–1384′9″	2′4″	Anhydrite and halite grading into an 8″ run of anhydrite. From 1383′3″ to 1384′7″ core is polyhalite with a 1″ band of anhydrite at 1383′4″. From 1384′7″ to the end anhydrite is the chief mineral with a little polyhalite.	53.20	8.54	16.05
		Interval of 75′1″.			
1459′10″–1461′1″	1′3″	First 1″ is halite with some polyhalite; remainder is chiefly polyhalite with inclusions of red halite and small patches of green clay.	79.10	11.25	14.20
		Interval of 7″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1461′8″–1463′4″	1′8″	A mixture of halite and polyhalite. Much of the halite has fine-grained polyhalite disseminated throughout.	83.60	9.90	11.83
1463′4″–1465′1″	1′7″	Halite with irregular seams and inclusions of polyhalite.	97.90	4.96	5.08
		Interval of 1′5″.			
1466′6″–1468′9″	2′3″	First 1″ is halite, which is followed by 1′10″ of polyhalite containing small quantity of anhydrite. From 1468′4″ to 1468′9″ the core is chiefly anhydrite with disseminated polyhalite.	63.00	10.90	17.30
1468′9″–1471′3″	2′6″	Polyhalite with anhydrite and a small quantity of halite.	53.40	10.20	19.12
1471′3″–1473′5″	2′2″	Polyhalite with halite and some anhydrite.	64.20	12.63	19.70
1473′5″–1475′4″	1′11″	Polyhalite with halite and a small quantity of anhydrite. The last 2″ of core is anhydrite with some halite.	64.40	10.68	16.58

Fourth Government Potash Test

Field notation: U. S. potash test, Texas No. 4.
Location: Sec. 7, block B-16, public-school land, Ector County, Tex., about 1000 feet south of the Metz station on the Connell ranch.
Elev. not available; top of salt 930 feet; T.D. 2098 feet.
Mineralogy by W. T. Schaller.
Analyses by R. K. Bailey and E. T. Erickson.
Boron analyses: 2 samples tested about 0.07 per cent of B_2O_3; 20 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 22 samples tested less than 0.05 per cent of Br.
Iodine analyses: 22 samples tested less than 0.05 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1154′4″–1154′5″	1″	Halite.	--------	--------	--------
1154′5″–1154′10″	5″	Polyhalite.	--------	--------	--------
1154′10″–1154′11″	1″	Halite with a little soft red clay and a little polyhalite.	--------	--------	--------
		Interval of 14′2″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1169′1″–1169′6″	5″	Anhydrite and a little halite.	----	----	----
1169′6″–1170′	6″	Polyhalite.	----	----	----
1170′–1170′4″	4″	Halite, speckled with polyhalite.	----	----	----
		Interval of 92′6″.			
1262′10″–1263′1″	3″	Anhydrite and halite.	----	----	----
1263′1″–1265′3″	2′2″	Halite with a little polyhalite. 11″ of core missing between 1263′1″ and 1264′8″.	----	----	----
1265′3″–1265′7″	4″	Polyhalite.	----	----	----
1265′7″–1265′9″	2″	Halite with a little polyhalite.	----	----	----
		Interval of 12′7″.			
1278′4″–1278′10″	6″	Anhydrite.	----	----	----
1278′10″–1279′4″	6″	Halite and anhydrite.	----	----	----
1279′4″–1280′3″	11″	Anhydrite.	----	----	----
1280′3″–1280′6″ 1280′6″–1281′2″	3″ 8″	Anhydrite and polyhalite. Polyhalite.	69.30	10.00	16.85
1281′2″–1281′7″	5″	Halite, anhydrite, and polyhalite.	67.40	2.60	3.86
1281′7″–1283′	1′5″	Polyhalite with a little anhydrite.	60.90	12.21	20.10
1283′–1283′10″	10″	Polyhalite and halite with a little anhydrite.	58.60	7.93	13.50
		Interval of 5′.			
1288′10″–1289′1″	3″	Halite and polyhalite.	----	----	----
1289′1″–1289′4″	3″	Anhydrite and halite.	----	----	----
1289′4″–1289′11″	7″	Anhydrite.	----	----	----
1289′11″–1290′2″	3″	Clay with anhydrite. Some magnesite.	----	----	----
		Interval of 10′4″.			
1300′6″–1300′10″	4″	Halite and anhydrite.	----	----	----
1300′10″–1300′11″	1″	Halite and polyhalite.	----	----	----
1300′11″–1301′4″	5″	Halite and polyhalite.	----	----	----
1301′4″–1302′10″	1′6″	Anhydrite and halite. Graphic structure.	----	----	----
1302′10″–1304′	1′2″	Polyhalite, anhydrite, and halite.	64.50	3.67	5.69

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1304′–1305′2″	1′2″	Polyhalite with a little anhydrite.	59.10	11.60	19.65
1305′2″–1306′7″	1′5″	Polyhalite with a little anhydrite.	58.70	12.10	20.65
1306′7″–1307′8″	1′1″	Anhydrite.	———	———	———
1307′8″–1308′	4″	Anhydrite and clay.	———	———	———
1308′–1309′5″	1′5″	Halite.	———	———	———
1309′5″–1309′8″	3″	Halite and polyhalite.	} 84.30	9.80	11.65
1309′8″–1310′5″	9″	Polyhalite with a little halite.			
1310′5″–1311′7″	1′2″	Polyhalite and halite.	91.80	7.75	8.44
1311′7″–1312′5″	10″	Polyhalite.	} 67.20	13.50	20.10
1312′5″–1312′8″	3″	Polyhalite and halite.			
		Interval of 4′9″.			
1317′5″–1317′8″	3″	Polyhalite with a little anhydrite.	———	———	———
		Interval of 52′10″.			
1370′6″–1370′9″	3″	Polyhalite.	———	———	———
1370′9″–1371′	3″	Polyhalite and halite.	———	———	———
1371′–1372′	1′	Halite and anhydrite.	———	———	———
1372′–1372′1″	1″	Polyhalite and anhydrite.	———	———	———
1372′1″–1372′5″	4″	Anhydrite.	———	———	———
		Interval of 17′9″.			
1390′2″–1391′	10″	Polyhalite and halite.	———	———	———
		Interval of 7′11″.			
1398′11″–1399′	1″	Polyhalite and halite.	———	———	———
1399′–1399′6″	6″	Polyhalite.	} 54.70	9.27	16.95
1399′6″–1399′8″	2″	Polyhalite and anhydrite.			
1399′8″–1400′	4″	Polyhalite.			
1400′–1400′6″	6″	Halite and polyhalite.	———	———	———
		Interval of 37′11″.			
1438′5″–1438′6″	1″	Anhydrite.	} 60.00	10.10	16.85
1438′6″–1439′5″	11″	Polyhalite.			
1439′5″–1441′8″	2′3″	Halite, polyhalite, anhydrite.	———	———	———
1441′8″–1443′7″	1′11″	Anhydrite.	———	———	———
1443′7″–1444′5″	10″	Polyhalite and halite.	———	———	———
1444′5″–1445′3″	10″	Halite and polyhalite.	———	———	———
1445′3″–1445′8″	5″	Halite and polyhalite.	———	———	———

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1445′8″–1445′11″	3″	Halite and anhydrite.	———	———	———
1445′11″–1446′1″	2″	Anhydrite.	———	———	———
		Interval of 111′.			
1557′1″–1557′8″	7″	Anhydrite with a little halite.	———	———	———
1557′8″–1558′	4″	Anhydrite and polyhalite.	———	———	———
1558′–1559′2″	1′2″	Polyhalite.	63.90	13.58	21.22
1559′2″–1559′10″	8″	Anhydrite with a little halite.	———	———	———
1559′10″–1561′11″	2′1″	Anhydrite.	———	———	———
1561′11″–1562′11″	1′	Polyhalite.			
1562′11″–1563′	1″	Halite with a little polyhalite.			
1563′–1563′2″	2″	Polyhalite.	74.70	12.00	16.07
1563′2″–1563′3″	1″	Halite with a little polyhalite.			
1563′3″–1563′4″	1″	Polyhalite.			
1563′4″–1564′2″	10″	Halite with a little polyhalite.	———	———	———
1564′2″–1564′6″	4″	Polyhalite.	———	———	———
1564′6″–1564′10″	4″	Halite with a little polyhalite.	———	———	———
1564′10″–1565′1″	3″	Anhydrite with a little polyhalite.	———	———	———
		Interval of 69′5″.			
1634′6″–1634′8″	1′2″	Halite with a little polyhalite.	———	———	———
1635′8″–1635′11″	3″	Polyhalite with a little halite.			
1635′11″–1637′	1′1″	Polyhalite.	67.20	13.10	19.49
1637′–1637′7″	7″	Polyhalite.			
1637′7″–1637′8″	1″	Polyhalite and anhydrite.			
1637′8″–1637′11″	3″	Anhydrite.	———	———	———
		Interval of 5′5″.			
1643′4″–1643′9″	5″	Anhydrite.	———	———	———
1643′9″–1643′11″	2″	Anhydrite and polyhalite.	———	———	———
1643′11″–1644′	1″	Clay.	———	———	———
1644′–1649′3″	5′3″	Halite and blebby polyhalite.	———	———	———
1649′3″–1650′3″	12″	Halite.	———	———	———
1650′3″–1651′2″	11″	Halite and blebby polyhalite.	———	———	———

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1651′2″–1651′8″	6″	Polyhalite with a little halite.	----	----	----
1651′8″–1652′1″	5″	Anhydrite.	----	----	----
		Interval of 78′10″.			
1734′11″–1735′9″	10″	Halite and blebby polyhalite.	----	----	----
1735′9″–1736′1″	4″	Polyhalite and anhydrite.			
1736′1″–1736′2″	1″	Glauberite.			
1736′2″–1736′11″	9″	Polyhalite and anhydrite.	54.70	9.55	17.48
1736′11″–1737′4″	5″	Polyhalite and anhydrite.			
1737′4″–1737′9″	5″	Polyhalite with a little anhydrite.			
1747′–1747′7″	7″	Halite and blebby polyhalite.	----	----	----
1747′7″–1747′9″	2″	Halite.	----	----	----
1747′9″–1748′4″	7″	Polyhalite.	----	----	----
		Interval of 34′9″.			
1783′1″–1785′3″	2′2″	Anhydrite with a little halite.		----	----
		Interval of 111′9″.			
1897′–1897′3″	3″	Polyhalite and halite.			
1897′3″–1897′11″	8″	Polyhalite.	71.90	11.30	15.72
1897′11″–1898′6″	7″	Polyhalite and halite.			
1898′6″–1898′11″	5″	Polyhalite.			
1898′11″–1899′9″	10″	Anhydrite.	----	----	----
		Interval of 33′1″.			
1932′10″–1935′7″	2′9″	Halite and blebby polyhalite.	----	----	----
1935′7″–1937′5″	1′10″	Polyhalite with a little halite.	73.40	12.00	16.38
1937′5″–1939′6″	2′1″	Polyhalite.	65.00	14.90	22.90
1939′6″–1942′4″	2′10″	Halite with a little polyhalite.	----	----	----
1942′4″–1943′1″	9″	Polyhalite with a little halite.	69.90	14.98	21.42
1943′1″–1943′4″	3″	Polyhalite and halite.	----	----	----
1943′4″–1945′	1′8″	Polyhalite with a little halite.	65.50	12.25	18.70
1945′–1945′3″	3″	Halite and polyhalite.	----	----	----
		Interval of 55′11″.			
2001′2″–2001′4″	2″	Anhydrite.	----	----	----

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2001'4"–2002'	8"	Polyhalite with a little anhydrite.	71.60	13.38	18.65
2002'–2002'4"	4"	Polyhalite and anhydrite.	......	......	......
2002'4"–2002'8"	4"	Alternating bands of polyhalite and anhydrite.	......	......	......
2002'8"–2002'11"	3"	Anhydrite.	......	......	......
2002'11"–2003'1"	2"	Polyhalite and anhydrite.	......	......	......
2003'1"–2003'2"	1"	Clay and halite.	......	......	......

Fifth Government Potash Test

Field notation: U.S. potash test, Texas No. 3.
Location: NW. ¼ sec. 16, block HH, G., C. & S. F. Ry. Co. survey, Crockett County, Tex., on Harris Bros.' ranch.
Elev. not available; top of salt 1161 feet (approx.); T.D. 1799 feet.
Mineralogy by E. P. Henderson.
Analyses by E. T. Erickson and J. J. Fahey.
Boron analyses: 1 sample tested about 0.07 per cent of B_2O_3; 23 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 24 samples tested less than 0.05 per cent of Br.
Iodine analyses: 24 samples tested less than 0.05 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1210'–1211'4"	1'4"	First 5" is halite with two 1" seams of polyhalite crossing the core. The next 4" consist largely of polyhalite and anhydrite rather intimately mixed. From 1210'9" to 1211'4" the core is halite with a few inclusions of polyhalite.	......	......	......
1211'4"–1213'	1'8"	From 1211'4" to 1211'8" the principal mineral is polyhalite with thin seams of halite crossing the core. From 1211'8" to 1212'3" considerable anhydrite and polyhalite is present with small blebs of halite scattered throughout. Some kieserite is also present. From 1212'3" to 1213' principal mineral is polyhalite; some anhydrite is present, and a small quantity of halite.	82.2	7.67	9.34

Interval of 80'11".

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1293′11″–1294′11″	1′	First 3″ consists of halite with a few inclusions of polyhalite. Next 6″ is polyhalite containing small seams of anhydrite. Last 3″ is halite with some polyhalite inclusions.	----	----	----
		Interval of 9′.			
1303′11″–1304′8″	9″	First 1½″ is halite with a few inclusions of polyhalite. A thin seam of greenish clay containing a little magnesite between the halite and the following 8″ layer of polyhalite. This layer of polyhalite contains some halite.	----	----	----
		Interval of 16′2″.			
1320′10″–1322′4″	1′6″	First 1″ is halite followed by a 1″ gradational band of polyhalite, clay, and halite. From 1321′ to 1321′5″ the core is halite with thin bands of polyhalite. Halite with contained red polyhalite appears reddish. From 1321′5″ to 1321′10″ the principal mineral is polyhalite with some halite. There is a small amount of clay and magnesite present toward lower end. Anhydrite from 1321′10″ to 1322′4″. Some polyhalite is present. Clay and magnesite increase toward end of this section.	----	----	----
		Interval of 35′11″.			
1358′3″–1359′5″	1′2″	First 1″ is halite, followed by a 2″ seam of anhydrite containing small quantity of polyhalite. From 1358′6″ to 1358′8″ a layer of halite. From 1358′8″ to 1358′10″ a layer of anhydrite which contains some halite and	----	----	----

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		a little polyhalite. This anhydrite makes a sharp wavy contact with an 8″ seam of polyhalite.			
		Interval of 11′1″.			
1370′6″–1371′6″	1′	First 1″ is halite and is followed by 11″ of polyhalite containing thin ill-defined seams of halite. Halite has the appearance of being replaced by polyhalite.	89.4	9.66	10.80
1371′6″–1372′7″	1′1″	A thin seam of polyhalite at upper end of core followed by halite to 1372′, where there is a layer containing considerable polyhalite and thin seams of halite, which appear to be somewhat replaced by the polyhalite. Some anhydrite in the polyhalite.	90.8	5.99	6.60
1372′7″–1374′	1′5″	Polyhalite containing seams of halite which appears to have been replaced by polyhalite. There is a small quantity of anhydrite present in the polyhalite. From 1373′2″ to 1374′ the core is largely halite with a ½″ seam of polyhalite at 1373′4″ and a 2″ seam of polyhalite at 1373′7″.	92.4	5.56	6.02
1374′–1375′2″	1′2″	Halite for 3″, followed by polyhalite. Some anhydrite at 1374′5″, which increases in amount until at 1374′7″ core is chiefly anhydrite. 1″ seam of polyhalite cuts through the anhydrite at 1374′9″. From 1375′1″ to 1375′3″ polyhalite making rather sharp contact with a band of anhydrite. There is a bleb of polyhalite in the anhydrite.	78.2	2.78	3.56
1375′2″–1375′7″	5″	Halite.	------	------	------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1375′7″–1376′	5″	Thin layer of anhydrite containing dark-red spots of polyhalite at upper end; rest of core is halite with only small inclusions of polyhalite.	----	----	----
1376′–1377′	1′	First 1″ is halite, which grades into a complex mixture of anhydrite, polyhalite, and halite. Numerous small, poorly defined layers of anhydrite, which appear to have been partly replaced by both halite and polyhalite. From 1376′11″ to 1377′2″ anhydrite and magnesite are the principal minerals.	70.6	5.85	8.29
		Interval of 80′1″.			
1457′1″–1457′8″	7″	Halite is the chief mineral, with some polyhalite and anhydrite occurring together in places. Much gray clay scattered through halite both in seams and as blebs.	----	----	----
1457′8″–1458′2″	6″	Halite is chief mineral; contains anhydrite and polyhalite in small quantities.	----	----	----
		Interval of 2′4″.			
1460′6″–1461′1″	7″	Halite containing small blebs of polyhalite grading into anhydrite. The anhydrite contains thin bands of polyhalite. Some halite included in the anhydrite.		----	----
		Interval of 28′6″.			
1489′7″–1490′6″	11″	Polyhalite with inclusions of halite. Last 3″ of core is halite with some polyhalite inclusions.	----	----	----
		Interval of 5″.			
1490′11″–1491′6″	7″	Halite with small inclusions of polyhalite. Thin irregular seams of polyhalite at lower end of core.	----	----	----
		Interval of 10′10″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1582′4″–1582′8″	4″	Halite with inclusions of polyhalite. A large bleb of dull-brown fine-grained anhydrite. 2″ layer of polyhalite containing seams of halite, also a seam of brown clay with halite inclusions.	......	......	......
		Interval of 6′4″.			
1589′–1589′10″	10″	Halite with inclusions of polyhalite. From 1589′4″ to 1589′10″ core is polyhalite with inclusions of halite.	......	......	......
		Interval of 66′10″.			
1656′8″–1657′1″	5″	Thin layer of halite making a rather sharp contact with polyhalite and anhydrite. Remainder of core is a complex intergrowth of anhydrite, halite, and some polyhalite.	......	......	......
		Interval of 11″.			
1658′–1658′6″	6″	Chief mineral is halite having a brecciated structure, and between these angular particles some polyhalite has been deposited.	......	......	......
1658′6″–1659′6″	1′	Principal mineral is anhydrite (extremely fine-grained) with some polyhalite and halite. Quantity of polyhalite is very small.			
		Interval of 22′7″.			
1682′1″–1683′1″	1′	Polyhalite with some halite at upper end and a thin seam of clay and magnesite at lower end.	68.4	13.52	19.78

Sixth Government Potash Test

Field notation: U. S. potash test, Texas No. 2.
Location: NE. ¼ sec. 100, T. C. Jones survey, Upton County, Tex., on the Sun-Burleson lease, 3 miles north of McCamey.
Elev. not available; top of salt 437 feet; T.D. 1501 feet.
Mineralogy by E. P. Henderson.
Analyses by R. K. Bailey and E. T. Erickson.
Boron analyses: 1 sample tested about 0.07 per cent of B_2O_3; 17 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 18 samples tested less than 0.05 per cent of Br.
Iodine analyses: 18 samples tested less than 0.002 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
631′7″–632′4″	9″	Halite with a few blebs of polyhalite for first 1½″, followed by a 2″ layer of polyhalite containing some halite. At 631′11″ the polyhalite ends abruptly, and the rest of run is coarse crystalline halite. An inclusion of anhydrite was noticed in the halite. The edge of the anhydrite contains some polyhalite and is colored red.	--------	--------	--------
632′4″–633′1″	9″	A band of polyhalite running in a vertical direction across coarse crystalline halite. Small anhydrite masses in the polyhalite. Last 4″ is polyhalite with halite and green clay inclusions.	94.10	5.22	5.53
633′1″–634′7″	1′6″	First 2″ is halite with finely disseminated polyhalite throughout, giving the halite a red color. Rest of run is polyhalite with considerable halite.	89.90	9.75	10.85
634′7″–637′3″	2′8″	Anhydrite with considerable halite throughout. Some polyhalite in the anhydrite. At 634′10″ a 1″ bed of polyhalite making sharp contact with the anhydrite. Some crystals of halite extend across this contact. Rest of core has a graphic structure in which the elongated	--------	--------	--------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		halite crystals are arranged in more or less horizontal beds with the long axis of the halite vertical. At 637′ the anhydrite is banded and polyhalite is beginning to appear.			
637′3″–638′1″	10″	Complex mixture of polyhalite and anhydrite. Considerable anhydrite present throughout run.	46.40	7.20	15.53
638′1″–640′6″	2′5″	Chiefly banded anhydrite with some polyhalite. At 639′ a 1″ band of red glauberite. From 639′4″ to 639′6″ a layer of banded anhydrite and magnesite with some clay, followed by banded glauberite, anhydrite, and some polyhalite. From 640′ to 640′6″ core is anhydrite and polyhalite.	55.00	3.62	6.57
		Interval of 103′.			
743′6″–745′	1′6″	First 6″ is anhydrite, some halite, and green clay. From 744′ to 744′7″ a layer of polyhalite containing some halite. From 744′7″ to 744′9″ anhydrite grading into coarse crystalline halite which contains blebs of polyhalite.	68.50	3.81	5.56
		Interval of 55′7″.			
800′7″–804′9″	4′2″	First 6″ is polyhalite with some halite. A thin bed of coarse crystalline halite at 800′10″. From 801′1″ to 802′1″ a layer of anhydrite with a little halite. Anhydrite grades into granular halite. A band of polyhalite at 802′10″, followed by granular halite. From 803′2″ to 804′9″ the core is anhydrite with considerable halite distributed throughout.	....	....	....

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
804′9″–807′4″	2′7″	Banded polyhalite, anhydrite and halite. From 805′3″ to 805′7″ coarse grained halite with blebs of polyhalite. From 805′7″ to 807′4″ core is banded anhydrite and polyhalite. Small elongated masses of halite, arranged across the core in layers with long axis of halite in the vertical direction.	83.50	3.09	3.70
		Interval of 36′11″.			
844′3″–845′8″	1′5″	First 1″ is dark halite containing small disseminated inclusions of anhydrite, followed by 3″ layer of polyhalite, which grades rather rapidly into anhydrite. Another 2″ layer of polyhalite at 845′. Rest of core is anhydrite with halite inclusions.	--------	--- ----	--- ---
		Interval of 33′7″.			
879′3″–879′6″	3″	Anhydrite and halite.	-- - - -	- ------	--------
		Interval of 22′1″.			
901′7″–903′6″	1′11″	First 3″ is polyhalite, followed by 3″ of granular halite with polyhalite blebs. Rest of core is polyhalite with small seams of halite and some anhydrite.	80.20	9.22	11.50
903′6″–906′	2′6″	Coarse crystalline halite with blebs of polyhalite.	97.20	1.49	1.53
906′–906′3″	3″	An intimate mixture of halite and anhydrite with some polyhalite.	76.40	2.94	3.86
906′3″–907′7″	1′4″	Anhydrite and halite. Some thin clay and magnesite layers at 906′11″. From 907′ to 907′5″ the anhydrite contains finely disseminated polyhalite. Last 1″ is a clay magnesite layer.	53.10	1.40	2.63
		Interval of 106′1″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1013′8″–1015′	1′4″	Coarse crystalline halite with a thin band of polyhalite between the halite and anhydrite. Anhydrite runs from 1013′9″ to 1014′3″ and contains some halite. From 1014′ 3″ to 1014′9″ a layer of polyhalite. From 1014′9″ to 1015′ coarse crystalline halite with a few blebs of polyhalite.	-	-	---- --
		Interval of 28′9″.			
1043′9″–1045′5″	1′8″	First 1″ is coarse crystalline halite; remainder of the core is composed of polyhalite with ill-defined seams of halite.	92.90	5.95	6.41
		Interval of 97′.			
1142′5″–1142′8″	3″	Anhydrite.	---- -- -	---- - -	--------
1142′8″–1144′11″	2′3″	Polyhalite and anhydrite intimately mixed. Some halite finely distributed throughout.	73.50	6.53	8.88
1144′11″–1145′5″	6″	Anhydrite with a band of halite containing anhydrite at 1145′. Remainder of core is anhydrite with blebs of halite.	- -----	- -	-- --
		Interval of 22′2″.			
1167′7″–1169′3″	1′8″	First 3″ is anhydrite with a little finely divided polyhalite. From 1167′10″ to 1168′8″ the core is polyhalite and anhydrite. At 1168′ a band of rounded polyhalite blebs. A thin seam of clay and magnesite at 1168′9″. Polyhalite grades into green clay at lower end.	54.90	10.00	18.20
		Interval of 40′8″.			
1209′11″–1211′3″	1′4″	Granular halite with inclusions of green clay and polyhalite. The quantity of polyhalite is greatest between 1210′4″ and 1210′10″. From 1210′10″ to 1211′3″ the core is	94.60	2.24	2.37

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		principally halite with inclusions of anhydrite. A 1″ layer of polyhalite at lower end of run.			
1211′3″–1213′3″	2′	First 1″ has a poorly defined seam of polyhalite in halite. Remainder of core is largely halite with considerable anhydrite distributed throughout as a lacy network of thin veins.	81.10	1.30	1.60
1213′3″–1215′2″	1′11″	Polyhalite with a few inclusions of halite. At 1214′ 8″ a 2″ layer of halite and anhydrite containing a bleb of polyhalite. The bleb is surrounded by a clayey anhydrite band that divides and encloses the bleb and then unites as a thin layer.	79.90	8.87	11.11
1215′2″–1216′	10″	Coarse crystalline halite with poorly defined seams of polyhalite, also small blebs. From 1215′9″ to 1216′ chief mineral is polyhalite with a few inclusions of halite.	97.00	2.02	2.08
		Interval of 20′5″.			
1236′5″–1236′7″	2″	Coarse crystalline halite with blebs of polyhalite. Thin seam of green clay.	....	....	....
1236′7″–1237′9″	1′2″	Halite with blebs of polyhalite.	95.60	3.42	3.67

Seventh Government Potash Test

Field notation: U. S. potash test, Texas No. 1.
Location: West side of sec. 4, William Teer survey, Upton County, Tex., on the Roxana-Hughes lease, 10 miles north of McCamey.
Elev. not available: top of salt 445 feet; T.D. 1230 feet.
Mineralogy by E. P. Henderson.
Analyses by R. K. Bailey and E. T. Erickson.
Boron analyses: 2 samples tested about 0.07 per cent of B_2O_3; 13 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 15 samples tested less than 0.05 per cent of Br.
Iodine analyses: 15 samples tested less than 0.002 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
582'–582'8"	8"	Anhydrite with irregular halite inclusions.	....	....	....
582'8"–584'	1'4"	First 3" consists of anhydrite with two seams of polyhalite. Some halite seams in the anhydrite. The halite appears to have reacted with the anhydrite. Remainder of core consists of anhydrite with several layers of polyhalite. Polyhalite appears to have replaced the anhydrite. Halite inclusions are present, generally in a horizontal layer. At 583'6" there is an irregular vein of glauberite. At 583'8" a 1" layer of polyhalite containing some halite. The remainder is composed of halite and anhydrite.	65.12	4.18	6.41
584'–585'2"	1'2"	Core is chiefly anhydrite; at upper end there is some polyhalite. Small quantity of halite scattered throughout run. At 584'8" is a layer containing considerable halite with specks of polyhalite.	57.66	1.98	3.43
		Interval of 48'3".			
633'5"–634'2"	9"	Small seam of clay making a sharp contact with anhydrite. From 633'7" to 633'11" is a layer of halite which contains considerable anhydrite finely distributed throughout the halite. Thin bands of clay, anhydrite, and magnesite at 634'. Last 2" is coarse crystalline halite with small brown mud inclusions.	....	....	....
		Interval 55'2".			
689'4"–689'7"	3"	Anhydrite and halite, making a sharp contact with the following material.	....	....	....
689'7"–691'3"	1'8"	Polyhalite from 689'7" to 691'3" containing a few	66.90	11.65	17.42

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		small seams of halite. At 691′2″ a 1″ layer of anhydrite containing glauberite, followed by magnesite.			
691′3″–692′6″	1′3″	From 691′3″ to 691′8″ thin beds of anhydrite cross the core; also one seam runs vertical. Anhydrite is reddish and contains polyhalite. A bleb of magnesite surrounded by glauberite and polyhalite at 691′8″. From 691′9″ to 691′11″ core consists of thin irregular bands of anhydrite, polyhalite, and magnesite. From 691′11″ to 692′2″ is glauberite, with a ¾″ vertical seam of halite, running the full distance. This glauberite is banded with thin layers of anhydrite. At 692′2″ a sharp contact is made with anhydrite. The ¾″ seam of halite practically ends at the beginning of the anhydrite, with the exception of a very thin seam which is continued into the anhydrite for 1½″. The anhydrite becomes richer in magnesite and clay toward bottom. Thin-bedded clay and magnesite with some halite at 692′4″ which grades into anhydrite containing polyhalite and halite.	53.70	3.76	7.00
		Interval of 8″.			
693′2″–693′7″	5″	Fine-grained anhydrite up to 693′7″; a sharp contact with polyhalite.	------	------	------
693′7″–694′3″	8″	Polyhalite from 693′7″ to 694′3″, making another sharp contact with anhydrite.	66.00	14.88	22.54
694′3″–694′6″	3″	Anhydrite.	------	------	------
		Interval of 49′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
743′9″–744′	3″	Halite containing blebs of polyhalite which grade gradually into polyhalite.	-------	-------	-------
744′–745′4″	1′4″	Polyhalite containing a few inclusions of halite.	75.40	12.71	16.87
745′4″–749′1″	3′9″	First 3″ is anhydrite containing some halite, followed by 2½″ of polyhalite and halite bands. From 745′9″ to 746′6″ halite and anhydrite; some of the halite is coarsely crystallized. Thin layers of polyhalite at 746′6″. From 746′7″ to 747′1″ halite with finely distributed anhydrite. From 747′1″ to 748′4″ anhydrite, with bands of halite. From 748′4″ to 749′ thin layers of anhydrite with rather coarse crystalline halite and a few layers of polyhalite. At 748′8″ some colorless glauberite.	-------	-------	-------
749′1″–749′8″	7″	Polyhalite with few inclusions of halite and anhydrite.	-------	-------	-------
749′8″–750′3″	7″	Coarse crystalline halite and anhydrite grading into banded anhydrite and polyhalite.	-------	-------	-------
		Interval of 34′4″.			
748′7″–785′3″	8″	Halite with small inclusions of polyhalite, followed by anhydrite containing colorless glauberite.	-------	-------	-------
785′3″–787′3″	2′	Polyhalite with a few thin beds of halite cutting across core. At 786′4″, 2″ of an intimate mixture of halite and anhydrite. Anhydrite at 786′9″ with a layer of polyhalite through it at 786′11″. Polyhalite with thin bands of green	63.40	9.91	15.64

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		clay crossing the core. Clay content increases with depth.			
		Interval of 33′3″.			
820′6″–821′7″	1′1″	Coarse crystalline halite with included blebs of polyhalite.			
821′7″–824′6″	2′11″	Coarse crystalline halite containing considerable included polyhalite.	96.64	3.14	3.24
824′6″–824′11″	5″	Anhydrite containing polyhalite.			
		Interval of 42′6″.			
847′5″–848′	7″	Coarse-grained halite with inclusions of polyhalite at 847′6″.			
848′–851′3″	3′3″	Sharp contact between halite and polyhalite. Coarse crystalline halite at 848′ 4″; remainder of core is polyhalite containing halite.	77.36	11.65	15.06
851′3″–851′5″	2″	Green sandy clay with seam of halite.			
		Interval of 2′1″.			
853′6″–854′10″	1′4″	First 2″ is halite with irregular inclusions of polyhalite. At 853′8″ the halite makes a sharp contact with anhydrite. The anhydrite contains a few horizontal seams of halite. Thin bands of red clay in the anhydrite from 854′4″ to 854′8″.			
		Interval of 3′9″.			
858′7″–860′11″	2′4″	Coarse crystalline halite with a few clay and polyhalite inclusions. At 859′ a layer about 1′ thick of polyhalite cuts across the core; also at 859′6″. At 859′7″ anhydrite becomes the principal mineral, with the halite and polyhalite making rather poorly defined layers. Polyhalite is confined to the anhydrite but occurs			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		next to the halite. From 860′5″ to 860′11″ chief mineral is polyhalite; some anhydrite and a little greenish clay appear at the lower end.			
		Interval of 93′1″.			
954′–954′6″	6″	Coarse crystalline halite with green clay inclusions at the contact of the halite and anhydrite. Clay, however, is confined to the halite. Anhydrite begins at 954′2″, and considerable halite is present.	------	------	------
954′6–955′11″	1′5″	Polyhalite. At 954′8″ a 2″ seam of halite and anhydrite crosses the core; the boundaries of seam not well defined. Remainder of core is polyhalite with halite inclusions.	73.58	10.78	14.65
955′11″–957′	1′1″	Coarse crystalline halite with inclusions of polyhalite.	96.60	3.68	3.81
		Interval of 29′6″.			
986′6″–987′6″	1′	Halite with inclusions of polyhalite. One crystal of halite exposed by splitting the core measures almost 2″ on cube face. From 986′8″ to 987′3″ core is chiefly polyhalite containing halite and a little disseminated anhydrite.	75.22	8.72	11.60
		Interval of 93′3″.			
1080′9″–1082′8″	1′11″	Coarse crystalline halite with polyhalite inclusions. At 1081′11″ a 3″ layer of polyhalite begins. From 1082′3″ to 1082′6″ granular halite with a few inclusions of polyhalite. Last 2″ is fine-grained anhydrite.	------	------	------
		Interval of 24′8″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1107′4″–1109′3″	1′11″	Granular halite grading into a 2″ band of polyhalite, followed by granular halite and a thin band of polyhalite at 1107′11″. From 1108′ to 1109′3″ a complex mixture of halite and anhydrite.	--------	--------	--------
1109′3″–1110′8″	1′5″	Polyhalite with small inclusions of halite.	51.38	12.42	20.24
1110′8″–1111′6″	10″	Thin-bedded anhydrite with some magnesite. Small inclusions of halite. Anhydrite grades into a 4″ layer of polyhalite containing halite inclusions. From 1111′3″ to 1111′6″ fine bedded anhydrite, magnesite, and clay.	--------	--------	--------
		Interval of 1′9″.			
1113′3″–1114′1″	10″	First 1″ is anhydrite, but it grades into polyhalite. A few ill-defined seams of halite present in the polyhalite.	65.18	7.83	12.02
1114′1″–1114′4″	3″	Anhydrite and halite in about equal quantities. At 1114′2″ a sharp contact is made with anhydrite of a darker color, which also contains clay and magnesite.	--------	--------	--------
		Interval of 26′.			
1140′4″–1141′6″	1′2″	Coarse crystalline halite containing inclusions of polyhalite and green clay. Quantity of polyhalite increases until at 1140′7″ a 4″ bed of polyhalite is encountered. Some clay at lower end of polyhalite bed. From 1140′11″ to 1141′6″ coarse crystalline halite with polyhalite inclusions.	--------	--------	--------
		Interval of 15′6″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1157′–1158′11″	1′11″	Polyhalite with small halite inclusions. At 1158′ the halite and anhydrite increase and grade into a halite and anhydrite bed.	70.14	12.04	17.17
1158′11″–1159′3″	4″	Graphic mixture of halite and anhydrite. The halite is arranged in interrupted bands across the core. Anhydrite becomes intermixed with clay and magnesite at lower end.	....	....	....

Eighth Government Potash Test

Field notation: U. S. potash test, Texas No. 5.
Location: SW. ¼ SW. ¼ sec. 5, block 14, University land, Crockett County, Tex.
Elev. not available; top of salt 468 feet; T.D. 1001 feet.
Mineralogy by E. P. Henderson.
Analyses by E. T. Erickson.
Boron analyses: 17 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 17 samples tested less than 0.05 per cent of Br.
Iodine analyses: 17 samples tested less than 0.002 per cent of I.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
521′1″–526′3″	5′2″	First 2″ is brown clay with small halite and anhydrite inclusions. At 521′3″ a 2″ layer of halite containing green clay inclusions and also polyhalite. All the minerals are rather intimately mixed. At 521′5″ a 3″ layer of polyhalite containing some halite. At 521′8″ an irregular seam of halite 2″ wide containing green clay inclusions cuts through the polyhalite. Both sides of this seam are free from clay. From 521′10″ to 524′6″ core is chiefly polyhalite with some halite seams included. From 524′6″ to 525′2″ a layer of halite containing small amount of polyhalite. Remainder of core is polyhalite.	87.96	6.35	7.14

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
526′3″–529′3″	3′	Coarse crystalline halite with irregular seams and inclusions of polyhalite. Thin brown clay seam at 527′3″. At 529′ a 1″ layer of polyhalite.	97.80	.48	.49
529′3″–529′8″	5″	Polyhalite with thin irregular seams of halite.	79.60	11.22	14.10
529′8″–530′7″	11″	Coarse crystalline polyhalite with thin ill-defined seam of polyhalite at 530′1″.	99.80	.77	.78
530′7″–530′11″	4″	Polyhalite with a very small quantity of green clay inclusions grading into halite and clay layer.	79.20	9.85	12.43
530′11″–531′4″	5″	First ½″ layer is a mass of halite with most of the crystals oriented at an angle of about 45° to the horizontal. Remainder is coarse crystalline halite with disseminated green clay inclusions, also a little polyhalite. Less than 1.5% of K_2O.	--	---	---
		Interval of 63′2″.			
594′6″–595′7″	1′1″	Granular halite grading into a layer containing irregular seams of polyhalite. At 595′ a 3″ layer of polyhalite begins. This layer contains some finely divided anhydrite.	99.90	1.44	1.45
595′7″–596′2″	7″	Polyhalite with smaller percentage of halite in unit orientation. Polyhalite appears to be replacing the halite.	88.44	9.35	10.57
596′2″–596′9″	7″	Halite in unit orientation in anhydrite. Some fine grained polyhalite is present. Appearance suggests that anhydrite is replacing some of the halite. Less than 1.5% of K_2O.	--	---	---
596′9″–597′5″	8″	Polyhalite: at lower end there is a layer of halite and green clay.	85.80	10.64	12.42
		Interval of 34′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
631′8″–632′	4″	Granular halite grading into polyhalite in the first 1″. At the lower end the polyhalite grades into green clay containing magnesite.	85.40	6.83	8.00
		Interval of 6′.			
638′–639′	1′	Granular halite with clay inclusions for 2″, followed by a 4″ layer of coarse crystalline halite with polyhalite inclusions. At 638′7″ a layer of brown clay followed by granular halite. Less than 1.5% of K_2O.	......	......	......
639′–639′3″	3″	Polyhalite containing some halite.	97.20	6.46	6.63
		Interval of 5′6″.			
644′9″–645′2″	5″	Granular halite grading into polyhalite. White anhydrite at 645′ appears to be altering to polyhalite.	90.20	5.88	6.43
		Interval of 5′8″.			
650′10″–651′	2″	Granular halite. Less than 1.5% of K_2O.	......	......	......
651′–651′9″	9″	Polyhalite with granular halite inclusions.	82.36	9.16	11.12
651′9″–652′2″	5″	Anhydrite and halite are the principal minerals. The anhydrite has long "stringers" intruding into the halite, a structure suggestive of replacement. The first piece contained a little polyhalite.	73.72	1.54	2.09
		Interval of 12′9″.			
664′11″–665′3″	4″	Anhydrite and halite. Many of the cleavage areas of halite are corroded and show anhydrite inclusions. Less than 1.5% of K_2O.	......	......	......
665′3″–666′8″	1′5″	Polyhalite with irregular halite veins. At 665′7″	88.50	5.33	6.03

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		some greenish clay inclusions in these halite veins. At 666′ a few veins of halite are free from clay, but from 666′4″ the polyhalite has inclusions of green clay. Last 2″ consists of magnesite clay with spherulites of polyhalite.			
		Interval of 11′10″.			
678′6″–678′10″	4″	Anhydrite with horizontal veins of halite. Less than 1.5% of K_2O.	....	....	....
678′10″–679′4″	6″	Polyhalite containing halite; last inch is halite with some polyhalite.	86.70	8.87	10.02
		Interval of 64′8″.			
744′–747′3″	3′3″	First 2″ is halite with clay inclusions, also some anhydrite. From 744′3″ to 745′ anhydrite and halite are the two principal minerals, and both are intimately mixed. A few seams and inclusions of polyhalite noticed. From 745′ to end anhydrite is practically free from halite. A little magnesite is distributed throughout core from 746′8″ to end. Less than 1.5% of K_2O.	....	....	....
		Interval of 10′11″.			
758′2″–759′1″	11″	First 2″ is granular halite with clay inclusions, also thin seams of anhydrite. Remainder is anhydrite with a very small quantity of polyhalite. Last inch is brownish clay containing magnesite, also seams of halite. Less than 1.5% of K_2O.	....	....	....
		Interval of 11′11″.			
771′–773′7″	2′7″	First 2″ is granular halite with clay inclusions. At 771′3″ a 3″ layer of polyhalite containing halite. This layer grades	89.00	2.41	2.71

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		rather gradually into anhydrite and halite. At 772′10″ this anhydrite-halite grades into polyhalite-halite layer, which runs to 773′6″. A thin seam of green clay at the bottom.			
		Interval of 9′11″.			
783′6″–784′8″	1′	First inch is granular halite with inclusions of clay containing magnesite. At 784′ a layer 2″ thick contains some polyhalite scattered through anhydrite. Above and below this layer of impure polyhalite is anhydrite. A band of magnesite and clay about 1″ thick at 784′5″.	64.50	.53	.82

Ninth Government Potash Test

Field notation: U. S. potash test, Texas No. 6.
Location: NW. ¼ SW. ¼ sec. 1, block 2, University land, Reagan County, Tex.
Elev. not available; top of salt 1104 feet; T.D. 1700 feet.
Mineralogy by E. P. Henderson.
Analyses by E. T. Erickson.
Boron analyses: 4 samples tested about 0.07 per cent of B_2O_3; 21 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 25 samples tested less than 0.05 per cent of Br.
Iodine analyses: 25 samples tested less than 0.002 per cent I.
Remarks: Log corrected and core reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1126′11″–1127′11″	1′	Chiefly halite with irregular inclusions of polyhalite.	99.5	2.52	2.53
		Interval of 48′7″.			
1176′6″–1178′6″	2′	In the first 3″ there is considerable green clay mixed with both halite and polyhalite. From about 1176′9″ to 1177′3″ the core is polyhalite with halite and green clay present. From 1177′	82.9	4.32	5.25

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		3″ to 1178′2″ blebby halite (blebs of polyhalite). From 1178′2″ to 1178′6″ is halite.			
		Interval of 1′10″.			
1180′4″–1181′7″	1′3″	First 2″ is halite. At 1180′ 6″ there is a sharp and wavy contact between halite and polyhalite. The polyhalite layer is only about 1″ thick. From 1180′6″ to 1181′ is a mixture of halite, anhydrite, and polyhalite. Again at 1181′ and up to 1181′2″ there is some polyhalite with thin bands of anhydrite crossing the core. The last 4″ is chiefly anhydrite, with clay at the end.	75.1	2.14	2.85
		Interval of 81′9″.			
1264′4″–1265′3″	11″	The first 2″ is halite, but from 1264′6″ to 1264′11″ there is a layer of polyhalite. Last 4″ is halite with inclusions of polyhalite.	99.2	3.72	4.12
		Interval of 5′.			
1270′3″–1271′11″	1′8″	Halite with an irregular seam of polyhalite associated with some green clay at 1270′6″. At 1270′ 8″ coarse crystalline halite. Starting at 1270′9″ a layer of polyhalite 1′2″ thick, with a few inclusions of halite at the lower end.	76.3	7.47	9.78
1271′11″–1272′6″	7″	Largely anhydrite with included halite. There is some clay at the lower end.	88.7	1.35	1.52
		Interval of 4′10″.			
1277′4″–1279′7″	2′3″	From 1277′4″ to 1277′10″ halite with included polyhalite. Polyhalite with some halite from 1277′ 10″ to 1278′7″. Between 1278′7″ and 1279′2″ a	80.6	4.48	5.56

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		layer of halite with irregular seams of anhydrite and small masses of polyhalite. A rather irregular layer of polyhalite from 1279′2″ to 1279′5″. The remainder is a brownish-red clay.			
		Interval of 29′5″.			
1309′–1309′3″	3″	Halite with blebs of polyhalite.	99.7	1.78	1.79
1309′3″–1310′9″	1′6″	Polyhalite with a few blebs of halite. A small bleb of magnesite at 1309′4″.	79.2	10.65	13.45
1310′9″–1311′3″	6″	Green clay. The top of the layer contains some polyhalite, and at 1311′2″ there is a sharp contact with halite.	39.2	1.45	3.70
		Interval of 29′7″.			
1330′10″–1333′4″	2′6″	Blebby halite from 1330′10″ to 1332′5″; the blebs are polyhalite. A band of polyhalite from 1332′5″ to 1333′1″; remainder is halite. There is a little anhydrite at the lower end of the polyhalite band.	98.8	2.51	2.54
		Interval of 18′8″.			
1352′–1353′3″	1′3″	The first piece has some green clay at the beginning; the remainder is halite with small inclusions of polyhalite. At 1352′10″ an irregular layer of polyhalite with halite inclusions. Last 2″ of run is halite with clay.	95.0	4.15	4.37
		Interval of 36′11″.			
1390′2″–1391′2″	1′	Halite for the first 1½″ grading into a polyhalite layer 5″ thick. An irregular layer of sandy clay cuts through the core at 1390′11.″ Remainder of run is halite with few blebs of polyhalite.	92.4	4.38	4.73
		Interval of 71′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1462′5″–1463′	7″	First 1″ is halite; remainder is polyhalite containing irregular seams of halite.	90.8	8.10	8.92
		Interval of 36′2″.			
1499′2″–1500′3″	1′1″	Halite with some polyhalite.	99.9	3.09	3.09
1500′3″–1501′2″	11″	Polyhalite with a little included halite.	86.2	9.40	10.10
1501′2″–1501′3″	1″	Halite and green clay.	83.9	.63	.75
		Interval of 14′9″.			
1516′–1518′1″	2′1″	Halite; a 1″ band of anhydrite at 1516′2″, with a little polyhalite around the outer boundary of the band. Between 1516′ 2″ and 1516′10″ the halite contains a number of irregular seams of polyhalite. From 1516′10″ to 1517′10″ repeated layers of polyhalite above anhydrite and clay below the anhydrite. Layer of clay from 1517′7″ to 1517′10″. Remainder is halite with clay inclusions.	76.9	1.35	1.76
		Interval of 7′9″.			
1525′10″–1526′2″	4″	An intergrowth of irregular seams of anhydrite and halite. The last inch shows a sharp wavy contact between anhydrite and polyhalite.	68.5	1.74	2.54
1526′2″–1528′2″	2′	Polyhalite with irregular halite seams.	74.4	10.85	14.60
1528′2″–1528′9″	7″	Halite with a few separated seams of polyhalite around 1528′6″.	99.6	3.18	3.19
		Interval of 82′.			
1610′9″–1611′7″	10″	Halite that becomes richer in polyhalite at the lower end.	98.0	3.34	3.41
1611′7″–1612′8″	1′1″	Polyhalite with some halite present.	81.9	9.55	11.68
1612′8″–1613′1″	5″	Coarse crystalline halite with clay inclusions.	97.0	1.06	1.09

Tenth Government Potash Test

Field notation: U. S. potash test, Texas No. 7.
Location: NE.¼ NE.¼ sec. 14, block 35, T. 2 S., T. & P. R.R. Co. survey, Glasscock County, Tex.
Elev. not available; top of salt 1283 feet; T.D. 1892 feet.
Mineralogy by E. P. Henderson.
Analyses by E. T. Erickson and J. J. Fahey.
Boron analyses: 1 sample tested about 0.07 per cent of B_2O_3; 24 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 25 samples tested less than 0.05 per cent of Br.
Iodine analyses: 25 samples tested less than 0.002 per cent of I.
Remarks: Log corrected and core reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1369′2″–1370′4″	1′2″	First 2″ is halite, followed by 2″ of lacy halite and polyhalite. From 1369′9″ to 1370′ a layer of polyhalite. Last 4″ is halite with some polyhalite seams and a small amount of kieserite.	94.4	5.65	6.00
		Interval of 1′1″.			
1371′5″–1372′3″	10″	Halite with a 2″ seam of polyhalite at 1371′8″ and a few small scattered seams of polyhalite at 1372′.	89.2	2.67	3.00
1372′3″–1373′5″	1′2″	Polyhalite.	66.0	13.88	21.03
1373′5″–1373′7″	2″	Halite.	97.4	.62	.64
		Interval of 39′11″.			
1413′6″–1414′2″	8″	First 4″ is halite with very little polyhalite; remainder is polyhalite with irregular halite seams.	95.8	4.45	4.65
		Interval of 14′2″.			
1428′4″–1428′10″	6″	Halite with an irregularly defined polyhalite layer.	96.8	2.40	2.48
		Interval of 3′10″.			
1432′8″–1434′9″	2′1″	First 2″ is halite, but starting at 1432′10″ there are numerous layers of anhydrite (graphic intergrowth of halite and anhydrite). Between 1434′ and 1434′6″ a layer of halite with a few seams of polyhalite. A 3″ seam	85.4	1.77	2.07

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		of polyhalite making a sharp but wavy contact with anhydrite at 1434′9″.			
		Interval of 87′9″.			
1522′6″–1524′3″	1′9″	Halite with a few small blebs of polyhalite, also several very irregular seams of anhydrite. At 1523′9″ the halite makes a sharp contact with the anhydrite. The anhydrite directly below the halite contact contains small inclusions of halite. At 1524′1″ a contact between two unusual types of anhydrite—brecciated anhydrite above and fine-grained, dense anhydrite below.	83.2	.79	.95
		Interval of 27′9″.			
1552′–1552′4″	4″	Halite.	96.6	1.10	1.14
1552′4″–1552′11″	7″	First 2″ contains some halite and few small blebs of kieserite. Remainder is polyhalite.	81.4	10.65	13.09
1552′11″–1553′2″	3″	Halite.	98.0	.54	.55
		Interval of 22′11″.			
1576′1″–1576′7″	6″	Halite with a little included polyhalite.	98.8	1.02	1.03
1576′7″–1577′6″	11″	Polyhalite.	62.5	15.12	24.20
1577′6″–1578′4″	10″	Graphic intergrowth of halite and anhydrite. A sharp contact between this anhydrite and halite at 1578′2″.	75.4	.65	.86
		Interval of 69′10″.			
1648′2″–1649′6″	1′4″	First 1″ is halite but the halite grades rapidly into anhydrite. Banded graphic anhydrite variably colored red and white. The last 1″ is a reddish-brown shale.	62.0	.55	.89
		Interval of 22′1″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1671′7″–1673′	1′5″	First 2″ is brown clay followed by a 2″ layer of anhydrite. From 1672′ to 1672′3″ a graphic intergrowth of anhydrite and halite. There is some polyhalite around the halite inclusions. From 1672′3″ to the end the core is largely anhydrite with irregular seams of halite.	68.4	.61	.89
1673′–1674′	1′	The first 3″ contains elongated angular halite inclusions in an anhydrite matrix. The anhydrite grades into polyhalite. At the lower end of this run the polyhalite grades into halite.	7.78	10.45	13.44
		Interval of 20′8″.			
1694′8″–1695′3″	7″	Graphic intergrowth of anhydrite and halite.	79.2	.46	.58
		Interval of 37′1″.			
1732′4″–1733′3″	11″	Halite containing some polyhalite. An irregular band of anhydrite at 1732′10″. A rather sharp contact of halite and anhydrite at 1733′, also at 1733′2″.	92.4	.54	.58
		Interval of 3′1″.			
1736′4″–1737′4″	1′	Largely halite with seams of anhydrite. There is a little polyhalite toward the lower end of the run.	96.6	.31	.32
1737′4″–1738′8″	1′4″	Polyhalite with included halite.	83.8	10.21	12.19
1738′8″–1738′11″	3″	A thin band of halite above 2″ of anhydrite; the last 1″ is green shale.	32.4	.63	1.95
		Interval of 29′5″.			
1768′4″–1769′6″	1′2″	First 7″ are halite with a little anhydrite. From 1768′11″ to 1769′3″ some polyhalite; remainder is	87.0	1.60	1.84

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		anhydrite and halite ending in a seam of clay.			
		Interval of 66′4″.			
1835′10″–1836′5″	7″	First ½″ is polyhalite. It grades into halite with several thin seams of polyhalite cutting across the halite, one at 1836′ 2″, another at 1836′4″.	97.4	4.20	4.31
1836′5″–1837′8″	1′3″	First 2″ is largely halite containing some anhydrite, but from 1836′7″ to 1837′2″ the core is anhydrite with the exception of a thin seam of halite at 1836′9″. At 1837′2″ a sharp but wavy contact between anhydrite and polyhalite. The polyhalite contains blebs of halite. Immediately below the polyhalite is a layer of green clay. From 1837′6″ to end of run the core is largely halite with a little clay and polyhalite included.	64.0	2.64	4.13

Eleventh Government Potash Test

Field notation: U. S. potash test, Texas No. 8.
Location: SE. ¼ SE. ¼ sec. 3, block B-25, public-school land, Crane County, Tex., on the Waddell ranch.
Elev. not available; top of salt 1081 feet; T.D. 2070 feet.
Mineralogy by W. T. Schaller.
Analyses by E. T. Erickson and J. J. Fahey.
Boron analyses: 7 samples tested about 0.07 per cent of B_2O_3; 39 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 46 samples tested less than 0.05 per cent of Br.
Iodine analyses: 46 samples tested less than 0.002 per cent of I.
Remarks: Log corrected and core reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1313′4″–1314′2″	10″	Polyhalite, with little halite.	81.3	11.00	13.50
1314′2″–1315′10″	1′8″	Halite, with little polyhalite.	98.2	1.59	1.62

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1315′10″–1316′10″	1′	Polyhalite, with little halite.	71.0	12.13	17.10
		Interval of 85′10″.			
1402′8″–1403′8″	1′	Anhydrite, with little halite.	45.5	.61	1.34
		Interval of 17′.			
1420′8″–1421′7″	11″	Polyhalite, anhydrite, and halite in separate layers.	86.4	3.32	3.82
		Interval of 2′5″.			
1424′–1429′	5′	Anhydrite and intergrowths of halite, with disseminated polyhalite 4′6″. Banded anhydrite 6″.	46.6	2.38	5.10
		Interval of 11′2″.			
1440′2″–1440′10″	8″	Anhydrite, polyhalite, and halite in separate layers.	85.5	2.90	3.39
		Interval of 44′8″.			
1485′6″–1486′	6″	Mixture of halite, polyhalite, and anhydrite.	76.1	2.78	3.65
		Interval of 25′5″.			
1511′5″–1511′10″	5″	Polyhalite with disseminated halite.	68.4	9.80	14.30
		Interval of 6′6″.			
1518′4″–1519′6″	1′2″	Polyhalite with a little halite and anhydrite.	60.0	11.75	19.60
		Interval of 31′6″.			
1551′–1555′9″	4′9″	Anhydrite, halite, and polyhalite in separate layers.	54.2	1.45	2.68
1555′9″–1557′1″	1′4″	Polyhalite.	70.9	11.95	15.10
1557′1″–1557′6″	5″	Anhydrite and halite, with very little polyhalite.	50.2	.72	1.43
1566′8″1567′7″	11″	Polyhalite and halite.	72.8	3.78	5.20
		Interval of 19′3″.			
1586′10″–1587′2″	4″	Anhydrite.	17.8	.09	.50
1587′2″–1587′11″	9″	Polyhalite.	53.4	12.15	22.80
		Interval of 2′.			
1589′11″–1590′3″	4″	2″ of halite above 2″ of polyhalite and halite.	86.2	3.62	4.20
		Interval of 57′1″.			
1647′4″–1649′3″	1′11″	Polyhalite, halite, and anhydrite.	92.9	1.69	.82
		Interval of 8′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1657′6″–1658′6″	1′	Halite and anhydrite.	82.6	.47	.56
1658′6″–1660′4″	1′10″	Polyhalite, anhydrite, and halite.	63.2	7.10	11.23
1660′4″–1661′8″	1′4″	Polyhalite.	60.7	14.10	23.20
1661′8″–1662′9″	1′1″	Polyhalite and anhydrite. A little clay and halite.	68.6	9.17	13.35
		Interval of 1′8″.			
1664′5″–1664′8″	3″	Halite and polyhalite.	97.7	4.80	4.92
		Interval of 3′1″.			
1667′9″–1668′4″	7″	Polyhalite and halite.	95.5	6.46	6.78
1668′4″–1670′4″	2′	Polyhalite and halite in layers with one band of anhydrite.	81.8	6.36	7.76
		Interval of 13′8″.			
1684′–1684′10″	10″	Anhydrite and halite.	86.5	1.30	1.50
		Interval of 32′9″.			
1717′7″–1717′11″	4″	Anhydrite and halite with a little polyhalite.	61.2	1.05	1.72
		Interval of 21′5″.			
1739′4″–1739′6″	2″	Halite.	97.7	.53	.54
1739′6″–1740′4″	10″	Polyhalite and halite.	93.0	5.05	5.43
1740′4″–1742′2″	1′10″	Anhydrite.	29.4	.53	2.14
		Interval of 106′6″.			
1848′8″–1850′	1′4″	Anhydrite with a little halite and very little polyhalite.	47.7	.39	.81
		Interval of 24′4″.			
1874′4″–1876′	1′8″	Anhydrite with a little halite.	32.5	.39	1.20
		Interval of 14′9″.			
1890′9″–1896′4″	5′7″	Anhydrite with halite and polyhalite.	34.6	2.67	7.71
1896′4″–1898′7″	2′3″	Polyhalite and anhydrite in bands with a little halite.	56.4	7.15	13.65
1898′7″–1900′6″	1′11″	Anhydrite with some halite and clay.	39.8	1.69	4.25
		Interval of 77′2″.			
1977′8″–1979′4″	1′8″	Anhydrite with polyhalite and halite.	59.3	2.95	4.98

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1979'4"–1981'	1'8"	Polyhalite.	66.6	13.40	21.80
1981'–1981'9"	9"	Shaly polyhalite, magnesitic shale, halite, and anhydrite.	75.8	7.95	10.50
		Interval of 28'4".			
2010'1"–2012'11"	2'10"	Polyhalite with anhydrite and halite.	70.1	9.06	12.90
2012'11"–2013'4"	5"	Halite.	97.1	1.25	1.29
2013'4"–2016'3"	2'11"	Halite with a very little polyhalite.	97.6	1.16	1.19
2016'3"–2019'2"	2'11"	Polyhalite with layers of halite.	83.9	7.68	9.17
		Interval of 35'1".			
2054'3"–2055'1"	10"	Anhydrite polyhalite and halite.	52.2	3.00	5.75
		Interval of 3'6".			
2058'7"–2058'9"	2"	Halite with a little gray shale. Less than 1.5% of K_2O.	-	---	
2058'9"–2059'3"	6"	Anhydrite.	39.1	1.01	2.58
2059'3"–2060'2"	11"	Polyhalite.	70.2	14.23	20.30
2060'2"–2060'6"	4"	Anhydrite and clay.	18.4	.29	1.58

Twelfth Government Potash Test

Field notation: U. S. potash test, Texas No. 9.
Location: NE. ¼ NE. ¼ sec. 33, block 75, public-school land, Winkler County, Tex., on the Leeman ranch.
Elev. not available; top of salt 1076 feet; T.D. 2752½ feet.
Mineralogy by W. T. Schaller.
Analyses by E. T. Erickson and J. J. Fahey.
Boron analyses: 8 samples tested about 0.07 per cent of B_2O_3; 57 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 65 samples tested less than 0.05 per cent of Br.
Iodine analyses: 65 samples tested less than 0.002 per cent of I.
Remarks: Log corrected and core reëxamined in part.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1334'1"–1334'6"	5"	Anhydrite and halite, with a little disseminated carnallite (?) occurring in blebs and veinlets.	90.2	1.06	1.17
		Interval of 7".			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1335′1″–1336′6″	1′5″	Dark-brown earthy clay with disseminated carnallite (not visible) containing halite cubes for 4″. Remaining 1′1″ is mixture of halite, brown clay, and carnallite. (Although KCl is present it is probably a by-product from carnallite on exposure of core.)	76.0	1.06	1.43
		Interval of 7′7″.			
1344′1″–1344′10″	9″	Halite, with a little disseminated reddish and dark reddish-brown carnallite (?). Also massive brown clay.	89.3	1.30	1.46
		Interval of 2′5″.			
1347′3″–1347′7″	4″	Halite, with some anhydrite and a little disseminated carnallite.	96.7	.67	.69
1347′7″–1351′7″	4′	Mixture of anhydrite, polyhalite, and kieserite, colored reddish in indistinct areas, blebs, and streaks by carnallite. A very little halite is present. Some of the anhydrite contains narrow streaks rich in kieserite and polyhalite, as at 1348′10″. These three sulphate minerals form a fine-grained intimate mixture. At 1351′ considerable polyhalite with only a little kieserite.	60.0	3.38	5.63
1351′7″–1354′2″	2′7″	Halite with a little disseminated carnallite. At 1353′8″ is a 1″ seam of anhydrite colored pink by carnallite.	98.3	1.59	1.62
1354′2″–1355′5″	1′3″	Anhydrite, polyhalite, and kieserite with disseminated carnallite and sylvite in irregular masses. The sylvite is colored reddish and brownish, like the carnallite, which in many places surrounds the sylvite as a narrow seam.	74.0	8.65	11.67

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		A little kieserite is with the sylvite. A 1″ seam of bluish-gray clay, with disseminated carnallite, at 1355′3″. The compact anhydrite at 1354′2″ to 1354′6″ probably contains some polyhalite.			
		Interval of 12′9″.			
1368′2″–1372′1″	3′11″	Halite with disseminated carnallite. Show of kieserite.	96.8	.87	.89
		Interval of 4′1″.			
1376′2″–1379′6″	3′4″	Halite with disseminated carnallite. Some green shale and kieserite.	97.7	.67	.68
		Interval of 51′1″.			
1430′7″–1431′	5″	Polyhalite and halite. Brick-red zones are mixtures of polyhalite, halite, and anhydrite.	92.2	3.28	3.55
		Interval of 58′10″.			
1489′10″–1491′6″	1′8″	Chiefly anhydrite with a little halite. White mass at 1489′11″ is magnesite.	35.4	.43	1.21
1491′6″–1496′1″	4′7″	Polyhalite, anhydrite, and kieserite with disseminated carnallite.	43.0	4.83	11.22
1496′1″–1497′8″	1′7″	Anhydrite, polyhalite, and kieserite with smaller quantity of disseminated carnallite.	42.0	1.45	3.45
1497′8″–1499′5″	1′9″	Polyhalite with irregular-shaped masses of kieserite and some anhydrite with very little carnallite.	51.3	4.25	8.27
1499′5″–1500′8″	1′3″	Anhydrite.	33.6	.38	1.13
1500′8″–1502′7″	1′11″	Halite with disseminated carnallite.	99.0	.67	.68
1502′7″–1504′	1′5″	Halite and bluish-gray clay with a little disseminated carnallite.	83.1	.69	.83
		Interval of 52′.			
1556′–1556′10″	10″	Polyhalite and halite.	87.6	9.65	11.00
		Interval of 19′2″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1576′–1578′	2′	Polyhalite, halite, and anhydrite.	86.8	5.35	6.16
		Interval of 42′.			
1620′–1623′6″	3′6″.	Polyhalite, anhydrite, and halite with very little disseminated carnallite.	66.7	7.73	11.57
		Interval of 27′4″.			
1650′10″–1653′11″	3′1″	Polyhalite, halite, and anhydrite with very little disseminated carnallite.	84.0	5.10	6.07
		Interval of 57′11″.			
1711′10″–1712′10″	1′	Anhydrite with a little polyhalite.	33.3	.77	2.31
1712′10″–1714′4″	1′6″	Polyhalite and anhydrite.	50.8	6.85	13.47
		Interval of 69′11″.			
1784′3″–1784′11″	8″	Anhydrite, halite, and polyhalite.	47.4	.68	1.43
		Interval of 10′9″.			
1795′8″–1796′6″	10″	Polyhalite and halite. Little anhydrite and green shale.	75.6	7.12	9.41
		Interval of 27′11″.			
1824′5″–1824′10″	5″	Polyhalite and halite.	86.0	8.70	10.12
1824′10″–1825′10″	1′	Halite. Less than 1.5% of K_2O.	----	----	----
1825′10″–1826′5″	7″	Polyhalite and halite.	87.8	7.90	9.00
		Interval of 6′.			
1832′5″–1835′4″	2′11″	Anhydrite with little disseminated polyhalite.	52.0	6.65	12.80
		Interval of 54′.			
1889′4″–1893′	3′8″	Polyhalite and anhydrite with a little halite.	86.8	8.50	9.70
1893′–1895′10″	2′10″	Anhydrite.	40.1	3.48	8.67
1895′10″–1896′10″	1′	Polyhalite and a little halite.	93.2	10.80	11.60
		Interval of 32′6″.			
1929′4″–1930′	8″	Halite and polyhalite.	97.7	2.90	2.97
		Interval of 25′6″.			
1955′6″–1955′10″	4″	Halite and polyhalite.	85.1	7.67	9.02
		Interval of 42′9″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1998′7″–1999′9″	1′2″	Polyhalite and halite.	88.6	10.08	11.35
		Interval of 29′2″.			
2028′11″–2029′9″	10″	Halite and polyhalite.	95.0	4.34	4.58
2029′9″–2030′11″	1′2″	Polyhalite.	68.7	12.83	18.65
		Interval of 4′8″.			
2035′7″–2036′1″	6″	Polyhalite and halite.	83.8	10.90	13.05
		Interval of 6′5″.			
2042′6″–2043′4″	10″	Polyhalite and halite.	93.7	7.80	8.33
		Interval of 20′3″.			
2063′7″–2064′1″	6″	Polyhalite and halite.	89.4	7.76	8.67
		Interval of 1′8″.			
2065′9″–2068′1″	2′4″	Polyhalite, halite, and anhydrite in layers.	95.0	3.67	3.86
		Interval of 29′7″.			
2097′8″–2098′11″	1′3″	Polyhalite with a little halite.	78.6	11.80	14.95
2098′11″–2100′5″	1′6″	Anhydrite with a little polyhalite.	43.0	5.55	12.90
		Interval of 20′1″.			
2120′6″–2121′7″	1′1″	Polyhalite with halite.	78.0	9.50	12.20
2121′7″–2123′11″	2′4″	Anhydrite with a little polyhalite and halite.	41.0	1.74	4.25
		Interval of 38′8″.			
2162′7″–2163′9″	1′2″	Polyhalite, halite, and anhydrite.	83.0	5.93	7.13
		Interval of 5′8″.			
2169′5″–2178′11″	9′6″	Mixture of anhydrite and polyhalite with a very little halite.	32.5	2.60	8.00
2178′11″–2182′	3′1″	Anhydrite and polyhalite.	34.4	4.68	13.60
2182′–2184′7″	2′7″	Anhydrite.	21.3	.10	.47
		Interval of 33′7″.			
2218′2″–2218′7″	5″	Polyhalite and halite.	88.2	10.35	11.74
		Interval of 34′6″.			
2253′1″–2257′1″	4′	Chiefly anhydrite with polyhalite. Halite at 2253′1″ to 2253′3″.	46.2	5.06	10.95
2257′1″–2259′7″	2′6″	Polyhalite.	62.6	13.95	22.30

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2259′7″–2263′1″	3′6″	Polyhalite and anhydrite.	48.4	8.26	17.06
2263′1″–2267′1″	4′	Anhydrite with a little polyhalite.	29.2	1.53	5.24
2267′1″–2270′6″	3′5″	Polyhalite.	48.6	8.59	17.67
2270′6″–2273′2″	2′8″	Anhydrite and polyhalite.	38.2	5.94	15.55
2273′2″–2276′9″	3′7″	Polyhalite and anhydrite.	41.8	6.90	16.50
2276′9″–2278′2″	1′5″	Anhydrite with very little polyhalite.	22.8	.73	3.20
		Interval of 3′8″.			
2281′10″–2285′9″	3′11″	Anhydrite and halite with a little polyhalite at 2282′6″ to 2282′9″.	40.4	.85	1.93
		Interval of 88′8″.			
2374′5″–2378′7″	4′2″	Mixture of polyhalite and halite. Richer seams of nearly pure polyhalite from 2375′1″ to 2375′6″ and from 2377′7″ to 2378′5″.	92.8	6.37	6.86
		Interval of 97′11″.			
2476′6″–2478′3″	1′9″	Polyhalite, anhydrite, and halite in layers.	60.2	6.24	10.37
		Interval of 84′9″.			
2563′–2563′6″	6″	Polyhalite and a little halite.	72.2	10.93	15.15
		Interval of 47′3″.			
2610′9″–2611′7″	10″	Polyhalite and halite in layers.	95.0	6.78	7.14
		Interval of 18′10″.			
2630′5″–2632′3″	1′10″	Polyhalite and halite with a little anhydrite.	75.8	10.98	14.50
		Interval of 104′9″.			
2737′–2740′	3′	Polyhalite with halite at beginning and anhydrite at end of run.	74.8	10.65	14.24
		Interval of 5′2″.			
2745′2″–2750′	4′10″	Anhydrite with a little polyhalite.	50.2	5.80	11.55

Thirteenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 4.
Location: NE. ¼ NE. ¼ sec. 5, T. 24 S., R. 31 E., Eddy County, N. Mex.
Elev. not available; top of salt 850 feet; T.D. 2139 feet.
Mineralogy by W. T. Schaller and John C. Reed.
Analyses by E. T. Erickson and J. J. Fahey.
Remarks: Log corrected and core reëxamined in part only.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
828′6″–830′7″	2′1″	First 4″ is polyhalite and halite. Mostly polyhalite between 828′10″ and 830′7″ with some halite between 829′3″ and 830′.	66.8	13.36	20.00
		Interval of 15′5″.			
846′–846′10″	10″	Halite with small amount of disseminated polyhalite.	98.4	1.30	1.32
846′10″–847′3″	5″	Polyhalite and halite in about equal proportions.	92.9	7.15	7.69
		Interval of 8′8″.			
855′11″–856′8″	9″	4″ of halite with a little polyhalite, followed by 5″ that is chiefly polyhalite.	94.0	5.20	5.54
		Interval of 1′7″.			
858′3″–858′11″	8″	Polyhalite with bands and disseminated patches of halite.	93.6	7.28	7.78
		Interval of 17′8″.			
876′7″–877′10″	1′3″	Alternating bands and mixed layers of polyhalite and anhydrite with some halite. A little gray clay is present near the top.	70.2	4.58	6.54
877′10″–879′5″	1′7″	Chiefly polyhalite with layers and blebs of halite.	74.8	10.22	13.70
879′5″–880′	7″	Halite.	98.8	1.69	1.71
		Interval of 11′.			
891′–891′2″	2″	Polyhalite and halite.	--------	--------	--------
		Interval of 30′6″.			
921′8″–922′6″	10″	Polyhalite with some halite to 922′. Next 3″ chiefly clay with some	48.8	5.50	11.25

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		magnesite. Next 1″ chiefly anhydrite. Last 2″ anhydrite and polyhalite mixed.			
		Interval of 45′7″.			
968′1″–969′8″	1′7″	First 2″ halite. From 968′ 3″ to 969′5″ chiefly anhydrite with some halite. Remainder of run is halite with some anhydrite.	56.4	.63	1.05
		Interval of 13′5″.			
983′1″–983′8″	7″	Halite with blebs of polyhalite.	98.5	1.85	1.88
983′8″–984′4″	8″	To 984′2″ chiefly polyhalite with some clay, halite, and anhydrite. The remainder is clay with a little anhydrite and halite.	68.2	6.37	9.35
		Interval of 6′11″.			
991′3″–992′4″	1′1″	Polyhalite and halite, some mixed and some in relatively pure layers to 992′ 1″. A paper-thin clay seam at 992′. Remainder of run is halite with a little clay.	93.9	4.35	4.65
		Interval of 12′4″.			
1004′8″–1005′9″	1′1″	Chiefly polyhalite to 1005′ 4″. Remainder is a mixture of halite and clay, which contains nodules of halite. Two thin layers of fibrous halite at 1005′9″.	86.7	4.82	5.55
		Interval of 4.5″.			
1010′2″–1010′10″	8″	Halite and polyhalite, the run terminating in brown clay.	84.0	8.10	9.65
		Interval of 21′7″.			
1032′5″–1032′7″	2″	Halite with disseminated polyhalite.	------	------	------
1032′7″–1034′2″	1′7″	Polyhalite with some halite.	79.8	11.90	14.91

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1034′2″–1034′5″	3″	Halite with a little polyhalite.	-------	-------	-------
		Interval of 18′1″.			
1052′6″–1053′	6″	First 1″ halite with some polyhalite. Remainder is chiefly polyhalite. Small amount of clay and magnesite toward end of run.	-------	-------	-------
		Interval of 11′8″.			
1064′8″–1065′4″	8″	Predominantly polyhalite to 1065′1″, with some halite and in last 1″ some anhydrite and an increased percentage of halite. Last 3″ clay with nodules and grains of halite and polyhalite. Polyhalite increases near end of run.	59.5	8.00	13.40
		Interval of 33′3″.			
1098′7″–1099′4″	9″	Halite with increasing proportions of anhydrite and a little polyhalite appearing in last few inches.	54.4	2.50	4.62
1099′4″–1101′6″	2′2″	From 1099′4″ to 1099′5″ halite and anhydrite and a little polyhalite. From 1099′5″ to 1101′6″ anhydrite and polyhalite with some halite. Anhydrite becomes more abundant toward end of run, where there are also a few narrow bands of magnesite.	62.8	10.02	16.10
1101′6″–1102′5″	11″	First 3″ anhydrite with some magnesite and a very little polyhalite and halite. Next 4″ gray shale containing a small amount of halite. Remainder of run anhydrite with a little halite.	24.8	.58	2.33
1102′5″–1103′4″	11″	Polyhalite with a little halite at the top.	68.4	14.30	20.95
1103′4″–1104′8″	1′4″	Mixed anhydrite and halite with a few nodules of polyhalite at the top. Several narrow bands of relatively pure halite, one 1″ wide at 1104′2″.	77.4	.96	1.24

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		Pseudo-morphous structure of halite after gypsum noticed at 1104′1″.			
		Interval of 5′8″.			
1110′4″–1112′9″	2′5″	Chiefly anhydrite which contains a few blebs of magnesite and a small amount of halite down to 1111′1″; then a 1″ layer of nearly pure halite followed by polyhalite with some halite to 1111′6″. From 1111′6″ to 1112′5″ chiefly anhydrite mixed with halite. Remainder of run is clay containing some magnesite, anhydrite, and halite.	73.8	1.93	2.62
		Interval of 47′3″.			
1160′–1160′2″	2″	Halite with a little disseminated polyhalite.	-------	-------	-------
1160′2″–1161′1″	11″	Chiefly polyhalite with considerable halite in which polyhalite is distributed.	86.8	8.70	10.01
		Interval of 10′.			
1171′1″–1171′4″	3″	Coarsely crystalline halite with a little polyhalite.	99.4	3.56	3.58
1171′4″–1171′9″	5″	Light-colored polyhalite with about 1″ of halite at the bottom.	85.8	9.75	11.35
		Interval of 17′7″.			
1189′4″–1192′2″	2′10″	First 1″ halite; considerable polyhalite with narrow bands and patches of halite to 1191′. Remainder of run is relatively pure polyhalite with a little halite; magnesitic clay at bottom.	79.0	11.78	14.92
		Interval of 33′6″.			
1225′8″–1226′3″	7″	First 2″ pure light-colored polyhalite. Remainder of run polyhalite and halite mixed.	82.6	8.50	10.28
1226′3″–1227′6″	1′3″	Halite and anhydrite mixed with a very small amount	71.2	1.54	2.16

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		of polyhalite at the top and bottom.			
1227′6″–1229′9″	2′3″	First 4″ chiefly red polyhalite with a little magnesitic clay near top. A little halite throughout, which becomes more conspicuous near 1227′10″. From 1227′10″ to 1228′8″ coarsely crystalline halite with disseminated polyhalite and a few narrow bands of anhydrite. From 1228′8″ to 1228′10″ halite with a little polyhalite. Remainder polyhalite and halite, mixed with magnesitic clay at the bottom.	90.6	4.80	5.29
		Interval of 12′10″.			
1242′7″–1244′6″	1′11″	From 1242′7″ to 1243′1″ chiefly anhydrite with a band rather rich in polyhalite at 1242′9″. One polyhalite nodule here has a peculiar concentric structure. From 1242′9″ to 1243′1″ anhydrite streaked horizontally by polyhalite. Remainder polyhalite and halite, with a small amount of anhydrite at top and bottom of run.	84.6	6.35	7.50
1244′6″–1246′2″	1′8″	To 1245′4″ a blebby mixture consisting for the most part of anhydrite and halite. The halite is stained with polyhalite, which is present in patches through the section, becoming more abundant near the bottom. From 1245′4″ to end of run chiefly polyhalite with some halite and a very little magnesite.	62.2	6.28	10.01
1246′2″–1246′3″	1″	Magnesitic clay with halite throughout.	34.2	4.20	12.30
		Interval of 5′11″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1252′2″–1252′4″	2″	Coarse halite with a very little polyhalite.	96.6	1.59	1.65
1252′4″–1252′10″	6″	Chiefly polyhalite with considerable halite.	90.7	8.97	9.90
		Interval of 7′11″.			
1260′9″–1260′11″	2″	Coarse halite containing some light polyhalite.	97.8	2.60	2.66
1260′11″–1261′2″	3″	Light polyhalite with small percentage of halite.	80.4	11.30	14.05
		Interval of 7′7″.			
1268′9″–1269′8″	11″	Polyhalite containing some halite to 1269′5″. Remainder chiefly halite containing considerable polyhalite in first half and much magnesitic clay in bottom half.	93.2	5.85	6.27
		Interval of 10′9″.			
1280′5″–1281′6″	1′1″	Chiefly light polyhalite with some red halite. A small mass of fine-grained pyrite at 1281′3″.	77.4	12.60	16.30
1281′6″–1284′8″	3′2″	Intimate mixture of anhydrite, polyhalite, and halite with local polyhalite bands richer than any others to 1284′3″. The polyhalite is mostly light-colored. Remainder of run is fine-grained flesh-colored polyhalite, which occurs as spherulites in magnesitic clay in first half of section and as massive polyhalite in last half, with a little clay at the bottom.	54.0	5.65	10.45
		Interval of 6′9″.			
1291′5″–1292′	7″	Polyhalite with a 1″ layer of halite below 1291′7″. Minor amounts of halite through the section.	87.6	9.60	10.95
1292′–1293′9″	1′9″	Chiefly brownish polyhalite speckled with glassy polyhalite. A few narrow layers of halite. A layer containing considerable	73.8	11.50	15.60

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		anhydrite from 1293′ to 1293′2″.			
		Interval of 87′.			
1380′9″–1381′11″	1′2″	Chiefly halite mixed with considerable polyhalite.	89.4	3.96	4.43
1381′11″–1384′	2′1″	Polyhalite to 1382′3″, with considerable coarsely crystalline halite. To 1383′1″ fine-grained polyhalite with a narrow white magnesite band at 1382′11″. At 1383′1″ an irregular contact marked with a little gray magnesitic clay, with more vitreous polyhalite to 1384′. Two narrow halite layers near bottom, and at the very bottom a thin parting of clay immediately overlain by half an inch of very fine grained polyhalite.	74.6	11.40	15.30
		Interval of 21′6″.			
1405′6″–1407′11″	2′5″	A mixture of polyhalite and halite with a little anhydrite.	88.6	9.55	10.78
1407′11″–1411′2″	3′3″	First 8″ practically pure polyhalite. Remainder high in polyhalite with small amounts of halite.	70.0	15.10	21.60
1411′2″–1412′8″	1′6″	Chiefly magnesitic clay with some halite and polyhalite to 1411′11″. Halite with a little polyhalite to 1412′7″. Remainder coarsely crystalline halite with a little polyhalite.	73.9	10.00	13.52
1412′8″–1413′6″	10″	Chiefly polyhalite mixed with some halite.	74.8	12.60	16.85
1413′6″–1413′11″	5″	Halite containing some polyhalite.	———	———	———
		Interval of 46′4″.			
1460′3″–1462′4″	2′1″	Polyhalite and halite to 1460′6″. Coarsely crystalline halite with disseminated polyhalite to 1461′	96.0	6.10	6.85

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		3″. Remainder chiefly polyhalite with some halite and clay through the last 3″.			
		Interval of 12′1″.			
1474′5″–1475′8″	1′3″	Chiefly halite with fine inclusions of polyhalite and two narrow bands of polyhalite at 1274′6″ and 1274′10″.	98.5	3.91	3.97
1475′8″–1478′1″	2′5″	Red polyhalite including a little halite and a little magnesite at 1476′6″. A large nodule (about 1″ in diameter) of polyhalite in polyhalite at 1477′8″.	71.6	12.80	17.85
1478′1″–1481′5″	3′4″	Coarsely crystalline halite with a little disseminated polyhalite.	98.0	2.90	2.96
1481′5″–1483′11″	2′6″	Chiefly coarsely crystalline halite with included polyhalite. Practically continuous as to material with last division.	98.6	2.60	2.64
1483′11″–1485′7″	1′8″	Chiefly polyhalite mixed with some halite, especially in the first 6″. A few thin partings of magnesitic clay within 3″ or 4″ of the bottom.	88.8	11.20	12.63
1485′7″–1486′	5″	Half an inch of magnesitic clay carrying halite and polyhalite at the top. Remainder coarse halite with a little polyhalite.	-------	----	---
		Interval of 31′9″.			
1517′9″–1520′	2′3″	To 1518′7″ chiefly light polyhalite with disseminated halite carrying some pink polyhalite. Anhydrite is also present. Remainder anhydrite with some polyhalite and halite.	66.4	5.50	8.28
1520′–1523′3″	3′3″	First 6″ anhydrite with some polyhalite and halite. Remainder a mixture	56.0	9.70	17.32

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		of grayish polyhalite with some anhydrite and a little halite.			
1523′3″–1525′8″	2′5″	First 9″ a mixture of grayish polyhalite with some anhydrite and a little halite. Remainder chiefly anhydrite with a little halite and polyhalite.	46.2	5.32	11.51
1525′8″–1530′	4′4″	Chiefly anhydrite. A little polyhalite from 1525′8″ to 1527′. In places anhydrite and magnesite are delicately interbanded. Some halite is present as occasional narrow bands and irregularly disseminated.	35.2	3.41	9.70
1530′–1534′3″	4′3″	Same as previous run with a little polyhalite in the last few inches.	25.8	.73	2.83
1534′3″–1534′10″	7″	First ½″ anhydrite with some polyhalite. Next 3″ polyhalite and magnesitic clay with a little halite. Remainder relatively pure polyhalite.	60.7	11.60	19.10
		Interval of 48′4″.			
1583′2″–1585′10″	2′8″	To 1584′1″ mostly halite carrying appreciable quantities of polyhalite. Anhydrite appears in minor amounts. First 6″ of remainder is anhydrite and halite with some polyhalite. The rest is mostly anhydrite carrying a very little halite and polyhalite.	83.8	2.22	2.65
1585′10″–1587′3″	1′5″	First 3″ anhydrite and polyhalite. Chiefly light-colored polyhalite with some halite and anhydrite to 1586′7″. Remainder anhydrite with a little halite and polyhalite.	66.4	6.20	9.34
1587′3″–1590′	2′9″	Anhydrite with a little halite and polyhalite.	31.9	1.64	5.15

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
1590′–1592′1″	2′1″	Coarsely crystalline halite with a few narrow bands of anhydrite and polyhalite.	49.6	1.45	2.92
1592′1″–1594′11″	2′10″	An intimate mixture of polyhalite, anhydrite, and kieserite. From 1592′10″ to 1593′ magnesite is present. Halite throughout most of the remaining section.	53.3	1.93	3.62
1594′11″–1597′11″	3′	An intimate mixture of polyhalite, anhydrite, and kieserite, with halite throughout most of the section in bands and as disseminated blebs.	50.8	5.97	11.73
1597′11″–1600′2″	2′3″	Mixture of polyhalite and anhydrite with a little halite. Magnesite is common in bands, some very thin, others over ¼″ thick.	49.0	5.40	11.01
1600′2″–1602′6″	2′4″	Mixture of polyhalite and anhydrite with a little halite. There are bands of magnesite throughout the run; one band 1″ thick carrying a little anhydrite at 1600′4″.	58.8	10.61	18.05
1602′6″–1603′10″	1′4″	Mostly magnesitic clay. A 2″ layer carries considerable polyhalite near the top of this section. Polyhalite and anhydrite are present in small quantities throughout.	25.6	1.74	6.70
		Interval of 6″, core lost.			
1604′4″–1604′7″	3″	Magnesite in clay with some polyhalite.	55.4	8.10	14.90
1604′7″–1605′3″	8″	Polyhalite with a little halite.	68.7	15.05	21.90
1605′3″–1605′7″	4″	First 2½″ clay with magnesite and halite. Remainder halite with a little magnesite and polyhalite.	88.8	4.05	4.56
		Interval of 25′10″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1631′5″–1634′6″	3′1″	First 6″ chiefly halite with some magnesitic clay and a little polyhalite and langbeinite. Remainder a mixture of halite, magnesite, and clay with langbeinite and a little sylvite.	90.6	2.22	2.45
1634′6″–1637′2″	2′8″	A mixture of red clay, halite, and langbeinite with a minor quantity of sylvite. Very good langbeinite from 1636′ to 1636′3″. Some polyhalite throughout the run.	76.4	3.72	4.87
1637′2″–1639′9″	2′7″	A mixture of langbeinite, clay, polyhalite, halite, and a little sylvite.	91.0	6.43	7.07
1639′9″–1642′9″	3′	To 1641′6″ a mixture of coarsely crystalline halite with langbeinite and a little polyhalite and sylvite. Sylvite becomes more abundant in the last half of this division and seems to surround many langbeinite masses. Remainder is halite, langbeinite, and sylvite with a little clay.	95.4	3.08	3.23
1642′9″–1645′8″	2′11″	Mostly coarsely crystalline halite carrying some sylvite and a little langbeinite. The first 8″ carries more langbeinite than the remainder.	98.4	2.51	2.55
1645′8″–1647′5″	1′9″	Same as above except that it has less sylvite.	97.4	3.58	3.68
1647′5″–1648′7″	1′2″	Chiefly halite to 1648′2″, carrying considerable polyhalite. langbeinite, and some sylvite. Remainder mostly polyhalite with a little halite.	95.2	6.65	6.98
1648′7″–1651′4″	2′9″	Mostly clay and halite to 1649′2″. A mixture of chiefly halite with some polyhalite to 1649′10″. A 2″ band relatively rich in polyhalite to 1650′. Remainder is halite containing a little polyhalite.	96.6	1.74	1.80

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1651′4″–1654′3″	2′11″	Chiefly halite with some polyhalite and a very little langbeinite and sylvite. Langbeinite especially prominent at 1653′6″.	95.6	2.51	2.63
1654′3″–1657′1″	2′10″	Mixture of halite with some clay, langbeinite, and sylvite. A good tetrahedron of langbeinite at 1656′6″.	97.2	2.17	2.23
1657′1″–1659′7″	2′6″	Coarsely crystalline halite with a little sylvite and some langbeinite.	95.8	2.85	2.97
1659′7″–1662′1″	2′6″	Coarse-grained halite with blebs of sylvite, langbeinite, polyhalite and possibly a little glauberite.	97.9	1.84	1.88
		Interval of 3′5″.			
1665′6″–1667′	1′6″	Mostly halite with gray clay and a little polyhalite.	95.4	1.93	2.02
		Interval of 8′.			
1675′–1675′11″	11″	Halite with blebs of sylvite and a little langbeinite.	98.8	6.85	6.95
1675′11″–1678′1″	2′2″	Halite, langbeinite, and sylvite. About one-half is langbeinite.	92.6	9.60	10.35
1678′1″–1682′7″	4′6″	Halite with blebs of sylvite and langbeinite.	96.2	2.66	2.77
1682′7″–1685′7″	3′	Halite and langbeinite.	88.4	5.50	6.23
		Interval of 10′8″.			
1696′3″–1698′5″	2′2″	Halite with blebs of sylvite. From 1696′4″ to 1696′7″ a layer of polyhalite. At 1696′9″ a bleb of white sylvite 1″ thick.	94.3	4.35	4.61
1698′5″–1702′4″	3′11″	Halite with blebs of sylvite mixed with clay, mostly brown, also a little langbeinite. At 1699′2″ to 1699′7″ considerable glassy langbeinite. From 1700′8″ to 1702′4″ triangular yellowish waxy-looking masses of kainite, pseudomorphs after	92.2	3.38	3.66

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		langbeinite. Leonite found by Calkins.			
1702′4″–1707′1″	4′9″	Pink halite with minor quantities of sylvite.	91.0	2.95	3.24
1707′1″–1710′3″	3′2″	Halite with a little sylvite.	94.4	2.61	2.76
1710′3″–1713′10″	3′7″	Halite with blebs of sylvite. The quantity of sylvite seems to be much less than in the preceding run.	96.6	2.26	2.34
1713′10″–1717′10″	4′	Halite with sylvite.	87.1	2.03	2.33
1717′10″–1718′9″	11″	Halite with sylvite.	97.5	2.51	2.57
1718′9″–1720′	1′3″	Nearly pure langbeinite with a little halite.	96.6	14.00	14.50
1720′–1723′3″	3′3″	Halite with langbeinite and sylvite.	97.2	2.32	2.38
		Interval of 10′2″.			
1733′5″–1736′2″	2′9″	Polyhalite with a little halite and anhydrite.	81.4	9.23	11.32
		Interval of 35′2″.			
1771′4″–1775′6″	4′2″	Gray polyhalite with both colorless and red halite.	81.8	5.97	7.30
		Interval of 29′11″.			
1804′5″–1805′8″	1′3″	Halite and polyhalite.	96.4	4.75	4.93
1805′8″–1807′3″	1′7″	Polyhalite with a little clay.	67.0	14.10	21.01
		Interval of 10′10″.			
1818′1″–1819′	11″	Polyhalite and halite.	94.7	7.20	7.60
		Interval of 36′.			
1855′–1855′10″	10″	Polyhalite and halite.	94.9	5.65	5.96
		Interval of 24′4″.			
1880′2″–1881′6″	1′4″	Polyhalite with a little halite.	78.0	11.70	15.00
		Interval of 19′3″.			
1900′9″–1901′7″	10″	Polyhalite and halite.	83.2	9.95	11.95
		Interval of 34′11″.			
1936′6″–1937′7″	1′1″	Polyhalite and halite with clay at the bottom.	75.4	8.83	11.05
		Interval of 7′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
1944′10″–1949′2″	4′4″	Halite with a little polyhalite scattered through it and in layers several inches thick.	99.6	2.37	2.32
1949′2″–1953′8″	4′6″	Halite with polyhalite blebs.	99.8	2.32	2.32
1953′8″–1959′11″	6′3″	Halite with prominent red polyhalite bands at 1954′ to 1955′ and 1957′11″ to 1959′11″.	92.0	5.17	5.63
		Interval of 26′9″.			
1986′8″–1988′8″	2′	Halite with some anhydrite and a little polyhalite.	90.5	2.08	2.30
1988′8″–1991′6″	2′10″	Anhydrite with a little halite.	49.5	.92	1.86
1991′6″–1993′	1′6″	Polyhalite with a little anhydrite.	50.1	9.22	18.38
1993′–1993′10″	10″	Anhydrite.	25.4	1.35	5.23
		Interval of 98′10″.			
2092′8″–2095′6″	2′10″	Polyhalite with some anhydrite.	73.5	4.30	5.98
2095′6″–2097′	1′6″	Polyhalite.	63.2	13.12	20.78
2097′–2100′10″	3′10″	Polyhalite with considerable anhydrite.	39.6	3.48	8.80
2100′10″–2102′3″	1′5″	Polyhalite with a decreasing proportion of included anhydrite.	50.5	9.26	18.35
2102′3″–2105′6″	3′3″	Polyhalite with a little anhydrite.	60.4	12.05	19.95
2105′6″–2107′11″	2′5″	Anhydrite with a little polyhalite and a 5″ layer of halite in the center.	66.8	1.88	2.81

Fourteenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 5.
Location: SW. ¼ SE. ¼ sec. 1, T. 26 S., R. 32 E., Lea County, N. Mex. The overburden above the top of the salt was drilled by the Humble Oil & Refining Co. on the Hinkle-Smith permit as a structure test.
Elev. 3326 feet; top of salt 1180 feet (approx.); T.D. 2096½ feet.
Mineralogy by E. P. Henderson.
Analyses by E. T. Erickson and J. J. Fahey.
Boron analyses: 5 samples tested about 0.07 per cent of B_2O_3: 44 samples tested less than 0.07 per cent of B_2O_3.
Bromine analyses: 49 samples tested less than 0.05 per cent of Br.
Iodine analyses: 49 samples tested less than 0.005 per cent of I.
Remarks: Log corrected and core reëxamined in part only.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
1184′–1185′1″	1′1″	The first 3″ is largely anhydrite with a small quantity of polyhalite and thin seams of clay. From 1184′3″ to 1184′9″ polyhalite with irregular seams of green clay. Between 1184′9″ and 1185′ 1″ halite containing polyhalite blebs.	83.2	6.78	8.15
		Interval of 29′11″.			
1215′–1216′3″	1′3″	Polyhalite with some anhydrite in the first 1″ and also at the lower end.	64.6	12.11	18.75
1216′3″–1216′7″	4″	Anhydrite.	26.4	.20	.75
		Interval of 27′5″.			
1244′–1244′9″	9″	A 1″ band of polyhalite at the top, followed by anhydrite and halite intergrowth. Last 3″ is chiefly polyhalite with some halite.	72.4	13.08	17.98
		Interval of 4′8″.			
1249′5″–1250′2″	9″	Polyhalite. A layer of halite at the top and a 2″ layer of blebby halite at the bottom. The main mass of polyhalite contains a little included halite.	91.4	8.44	9.24
		Interval of 20′.			
1270′2″–1272′	1′10″	Halite with a very small quantity of polyhalite. Between 1269′9″ and 1271′ the halite is richer in polyhalite. From 1271′ to 1271′4″ a layer of halite free from polyhalite. Blebby halite from 1271′ 4″ to end of core.	98.8	1.55	1.57
		Interval of 8′6″.			
1280′6″–1281′7″	1′1″	Anhydrite with a little halite.	43.6	.23	.53
1281′7″–1282′5″	10″	Polyhalite with a little anhydrite. The polyhalite ends with a band of green clay followed by layers of halite.	65.6	11.08	16.90

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1282′5″–1282′6″	1″	Halite with a very small quantity of polyhalite.	-----	-----	-----
		Interval of 21′2″.			
1303′8″–1304′11″	1′3″	Blebby halite. These blebs of polyhalite are rather large.	98.0	2.91	2.97
		Interval of 36′8″.			
1341′7″–1343′	1′5″	Anhydrite with inclusions of halite. A little polyhalite in the anhydrite between 1341′11″ and 1342′4″.	56.6	3.25	5.75
		Interval of 62′11″.			
1405′11″–1407′1″	1′2″	The first 3″ is blebby halite, followed by a 2″ layer of anhydrite which grades into a 3″ layer of polyhalite, containing inclusions of halite. The polyhalite grades into blebby halite.	87.6	4.80	5.48
		Interval of 29′11″.			
1437′–1437′3″	3″	Halite grading into polyhalite at lower end.	99.6	2.27	2.28
1437′3″–1439′1″	1′10″	Polyhalite with a small quantity of halite.	78.8	12.03	15.27
		Interval of 22′6″.			
1461′7″–1462′3″	8″	First 4″ is blebby halite. At 1461′11″ there is a sharp contact between this blebby halite and the following 4″ layer of polyhalite.	90.0	6.40	7.12
		Interval of 20′8″.			
1482′11″–1484′7″	1′8″	1″ of halite on a 6″ layer of light-gray polyhalite followed by halite from 1483′6″ to 1484′3″. A 2″ band of polyhalite begins at 1484′3″.	95.0	6.09	6.41
		Interval of 13′.			
1497′7″–1500′6″	2′11″	Anhydrite with inclusions of halite. There is an appreciable quantity of polyhalite throughout.	46.6	4.41	9.47

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1500′6″–1502′8″	2′2″	Anhydrite with some included halite. Practically no polyhalite.	52.6	1.27	2.42
		Interval of 26′.			
1528′8″–1529′10″	1′2″	Polyhalite except 1″ of halite at top.	76.8	13.78	17.95
1529′10″–1530′	2″	Halite with a 1″ layer of anhydrite.	84.8	2.45	2.89
		Interval of 2′7″.			
1532′7″–1533′5″	10″	Anhydrite with included halite and small quantities of polyhalite. Considerable clay between 1533′1″ and 1533′4″. A 1″ layer of halite at 1533′4″.	51.6	4.26	8.26
1533′5″–1535′7″	2′2″	Polyhalite. At 1533′6″ a 2″ layer of halite, and at 1534′ a 3″ layer of halite.	79.6	12.01	15.10
		Interval of 28′9″.			
1564′4″–1564′11″	7″	Polyhalite. The last 1″ is halite.	86.8	10.68	12.31
		Interval of 27′3″.			
1592′2″–1592′8″	6″	Halite with very little polyhalite; a few clay seams. Last 2″ polyhalite.	96.0	5.55	5.78
		Interval of 39′5″.			
1632′1″–1632′4″	3″	Halite with some polyhalite.	99.4	2.22	2.23
1632′4″–1633′11″	1′7″	Polyhalite with seams of halite.	76.6	12.45	16.25
		Interval of 21′6″.			
1655′5″–1656′	7″	First 2″ halite, followed by a 3″ layer of polyhalite. Remainder is halite.	95.6	5.74	6.00
		Interval of 1′11″.			
1657′11″–1658′2″	3″	Halite with a few inclusions of polyhalite.	98.6	2.21	2.24
1658′2″–1660′6″	2′4″	Polyhalite relatively free of halite inclusions except in first 6″.	85.4	11.82	13.85
1660′6″–1662′4″	1′10″	Anhydrite with bands of magnesite and halite inclusions. Below 1661′3″	64.6	9.87	15.28

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
		polyhalite is the principal mineral.			
1662′4″–1664′7″	2′3″	Polyhalite. Between 1663′ 2″ and 1663′7″ considerable included clay.	67.2	14.03	20.89
		Interval of 34′6″.			
1699′1″–1700′4″	1′3″	Halite with a 1″ layer of polyhalite at 1699′2″ and a 4″ layer of polyhalite at 1699′8″. Remainder halite.	95.6	4.62	4.83
		Interval of 20′2″.			
1720′6″–1720′10″	4″	First 2″ halite; remainder polyhalite.	99.4	6.82	6.86
		Interval of 2′5″.			
1723′3″–1724′1″	10″	First 5″ largely halite with considerable polyhalite; remainder polyhalite with small veins of halite.	85.2	9.58	11.24
		Interval of 16′8″.			
1740′9″–1744′7″	3′10″	Polyhalite with thin veins of halite.	73.6	13.43	18.25
1744′7″–1746′2″	1′7″	Anhydrite with some halite. Clayey band between 1744′9″ and 1745′1″.	31.0	1.08	3.48
1746′2″–1747′	10″	Polyhalite with thin seams of clay.	61.6	13.49	21.90
		Interval of 37′6″.			
1784′6″–1785′10″	1′4″	First 3″ contains a little polyhalite; remainder anhydrite with some halite.	53.4	2.19	4.10
1785′10″–1789′	3′2″	4″ of polyhalite with inclusions of halite; remainder polyhalite. A small quantity of anhydrite is present; some magnesite at 1788′5″.	57.2	11.19	19.58
1789′–1798′8″	9′8″	Anhydrite with some halite at 1790′6″; at 1794′11″ and 1795′11″ layers of anhydrite a few inches thick containing blebs of polyhalite.	33.8	2.25	6.66
		Interval of 18′11″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1817′7″–1818′1″	6″	Polyhalite with a seam of blebby halite at 1817′8″.	85.2	9.88	11.60
		Interval of 38′8″.			
1856′9″–1858′9″	2′	Anhydrite containing a little halite.	37.0	2.13	5.76
1858′9″–1862′	3′3″	Polyhalite.	65.0	13.62	20.97
1862′–1865′	3′	Anhydrite with inclusions of halite.	46.4	1.70	3.67
1865′–1867′6″	2′6″	First 3″ contains anhydrite, which grades into polyhalite.	60.8	10.21	16.80
1867′6″–1870′3″	2′9″	First 4″ contains more anhydrite than polyhalite; remainder richer in polyhalite than anhydrite.	47.4	6.59	13.90
1870′3″–1872′6″	2′3″	Anhydrite with a small bleb of polyhalite. Numerous small inclusions of halite.	33.2	3.50	10.55
1872′6″–1877′4″	4′10″	Between 1872′6″ and 1873′ 9″ anhydrite with halite inclusions. Anhydrite from 1873′9″ to end of this run. There are many thin bands of magnesite in this section. The anhydrite in the last 8″ contains considerable clay.	35.0	.97	2.77
		Interval of 46′1″.			
1923′5″–1924′	7″	Polyhalite with lenticles of halite within the upper half and 2″ of halite at the base.	94.6	7.95	8.40
		Interval of 102′6″.			
2026′6″–2029′9″	3′3″	First 6″ contains considerable halite. Remainder is polyhalite. Last 3″ contains green clay and halite along with the polyhalite.	77.2	12.89	16.70

Fifteenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 6.
Location: NE. ¼ NE. ¼ sec. 34, T. 21 S., R. 28 E., Eddy County, N. Mex.
Elev. 3177 feet; top of salt 517 feet; T. D. 1079½ feet.
Mineralogy by J. C. Reed.
Analyses by E. T. Erickson and J. J. Fahey.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
582′–583′2″	1′2″	Red polyhalite with a few narrow partings of halite. First 1″ relatively rich in halite. Last ½″ is halite with some clay.	75.6	11.40	19.05
		Interval of 21′5″.			
604′7″–605′1″	6″	Chiefly halite stained red with polyhalite. A few narrow strips of polyhalite in sample. Less than 1.5% of K_2O.	--------	--------	--------
605′1″–606′	11″	Chiefly fine-grained red polyhalite. A little magnesite at 605′11″. A small quantity of halite.	72.4	15.32	21.20
		Interval of 8′3″.			
614′3″–615′11″	1′8″	First 2″ halite and polyhalite mixed. Next 7″ practically pure polyhalite. From 615′2″ to end of run mostly polyhalite with some magnesitic clay in stringers and blebs, especially in last 2″.	66.4	13.20	19.85
		Interval of 2′9″.			
618′8″–619′1″	5″	2″ of red polyhalite with 3″ of halite and polyhalite blebs included in qualitative analysis of less than 2% of K_2O.	--------	--------	--------
		Interval of 43′5″.			
662′6″–663′1″	7″	Anhydrite with a very little polyhalite. Less than 1% of K_2O.	--------	--------	--------
663′1″–664′7″	1′6″	Polyhalite with an increasing amount of magnesite downward.	67.2	12.93	19.25

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
664′7″–664′10″	3″	Chiefly magnesitic clay. Less than 1% of K_2O.	......	......	......
		Interval of 20′4″.			
685′2″–687′7″	2′5″	Halite with considerable blebby polyhalite to 686′ 1″, followed by anhydrite with some polyhalite to 686′4″. Remainder mixed halite and polyhalite. Less than 1% of K_2O.	......	......	......
687′7″–688′8″	1′1″	Red polyhalite with some halite.	87.2	9.45	10.83
688′8″–689′2″	6″	Halite. Less than 1% of K_2O.	......	......	......
		Interval of 22′10″.			
712′–714′9″	2′9″	First 3″ polyhalite and halite mixed, followed by red polyhalite with a very little halite to 712′ 9″. Then nearly pure red polyhalite with a little anhydrite to 713′9″. Remainder has an increasing amount of anhydrite and a little halite mixed with the polyhalite.	64.6	9.85	15.25
714′9″–715′5″	8″	Red polyhalite followed by 4″ of halite. Less than 1% of K_2O.	......	......	......
715′5″–716′7″	1′2″	Red polyhalite with considerable anhydrite and some halite, especially near bottom.	73.0	7.14	9.77
716′7″–717′	5″	Anhydrite with a very little polyhalite. Less than 1.5% of K_2O.	......	......	......
		Interval of 6′9″.			
723′9″–724′2″	5″	2″ of halite with some anhydrite followed by 3″ of polyhalite and halite with some polyhalite blebs. Less than 1.5% of K_2O.	......	......	......
724′2″–725′4″	1′2″	Gray anhydrite with ¼″ halite band at bottom. Less than 1% of K_2O.	......	......	......
		Interval of 70′7″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
795′11″–796′4″	5″	Almost entirely halite with an amethystine color in places. Some anhydrite. Less than 1% of K_2O.	———	———	———
		Interval of 15′6″.			
811′10″–812′1″	3″	Halite chiefly. Less than 1% of K_2O.	———	———	———
812′1″–813′	11″	Polyhalite with considerable halite and some anhydrite. First 1″ chiefly halite.	86.0	5.20	6.05
813′–814′6″	1′6″	Chiefly anhydrite with several bands of fine flesh-colored halite near top and a 1″ layer of coarser halite at end of run. Some magnesite near middle of run. Less than 1% of K_2O.	———	———	———
		Interval of 32′11″.			
847′5″–849′10″	2′5″	Anhydrite and halite to 848′8″. Remainder of core practically pure anhydrite. Less than 1% of K_2O.	———	———	———
849′10″–852′	2′2″	Mixture of gray anhydrite and halite. Halite appears to be imperfectly pseudomorphous after gypsum. Some of the pseudomorphs over 1″ long. Less than 1% of K_2O.	———	———	———
852′–855′	3′	Same as above but carries an increasing amount of polyhalite downward.	51.8	3.86	7.45
855′–856′4″	1′4″	Mostly pink or salmon-colored polyhalite with considerable mixture of coarse halite and some anhydrite.	71.4	4.15	5.82
856′4″–858′1″	1′9″	Anhydrite and magnesite for first 10″, followed by 8″ of fine-grained anhydrite. Remainder mostly clay. A little halite throughout. Less than 1% of K_2O.	———	———	———
		Interval of 41′8″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol.ble salts
899'9"–901'6"	1'9"	Polyhalite, halite, and anhydrite for first 4", followed by anhydrite with some halite. 3" of clay at base. Less than 1.5% of K_2O.	----	----	----
		Interval of 37'.			
938'6"–940'7"	2'1"	Anhydrite with a few bands of halite and a little gray polyhalite near bottom. Less than 1% of K_2O.	----	----	----
940'7"–943'1"	2'7"	Polyhalite with a few bands of halite and some anhydrite near bottom.	65.0	10.70	15.45
943'1"–943'3"	2"	Anhydrite. Less than 1% of K_2O.	----	----	----
		Interval of 31'2".			
974'5"–975'1"	8"	First half nearly pure anhydrite; last half chiefly magnesitic clay with anhydrite. Less than 1% of K_2O.	----		----
975'1"–976'	11"	First 5" halite with a little polyhalite. Remainder halite, anhydrite, and some polyhalite. Less than 1% of K_2O.	----	----	----
976'–976'7"	7"	First 2" anhydrite with some halite. Next 3" almost pure anhydrite. Remainder of run anhydrite and clay. Less than 1% of K_2O.	----	----	----

Sixteenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 7.
Location: Center of SE. ¼ sec. 12, T. 14 S., R. 28 E., Chaves County, N. Mex.
Elev. 3623 feet (approx.); top of salt 364 feet; T.D. 514 feet.
Mineralogy by J. C. Reed.
Analyses by E. T. Erickson and J. J. Fahey.
Remarks: Log corrected but core not reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
371'–372'11"	1'11"	Halite with some polyhalite for first 5", followed by polyhalite with some halite and some anhydrite.	83.8	5.63	6.72

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
372′11″–375′7″	2′8″	Polyhalite with some halite. Last 2″ clay and halite. A little kieserite.	72.8	12.10	16.63
		Interval of 7′.			
382′7″–383′1″	6″	Halite with a very little polyhalite. Less than 1% of K_2O.	-------	-------	-------
383′1″–383′7″	6″	Light-colored polyhalite with a little halite near bottom.	71.8	13.90	19.35
383′7″–383′8″	1″	Red clay and halite. Less than 1% of K_2O.	-------	-------	-------
		Interval of 49′5″.			
433′1″–434′7″	1′6″	Mixture of halite, red clay, and kieserite, with perhaps a little polyhalite. Less than 2% of K_2O.	-------	-------	-------
434′7″–437′10″	3′3″	Halite with a greater abundance of kieserite, much of it in triangular pieces about ½″ across. Tetrahedral shapes of kieserite masses suggest kieserite after langbeinite. Less than 3% of K_2O.	-------	-------	-------
437′10″–441′	3′2″	Halite with kieserite and a little clay, especially in last 1′ of core. Some polyhalite distributed throughout. Less than 1% of K_2O.	-------	-------	-------
		Interval of 54′.			
495′–496′6″	6″	3″ of halite, followed by a 3″ band of polyhalite. Less than 2% of K_2O.	-------	-------	-------
		Interval of 3′4″.			
498′10″–499′1″	3″	Clay, with polyhalite and halite. Some anhydrite. Less than 1% of K_2O.	-------	-------	-------
		Interval of 5′7″.			
504′8″–505′3″	7″	Anhydrite with some polyhalite. Halite at top and bottom of section. Less than 1% of K_2O.	-------	-------	-------
		Interval of 3′7″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
508′10″–510′2″	1′4″	Halite with red clay for 1″. Polyhalite and anhydrite with some halite. Last 1″ pure red polyhalite.	52.2	.97	1.86

Seventeenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 8.
Location: NE. ¼ sec. 28, T. 20 S., R. 33 E., Lea County, N. Mex. This location is identical with that of the Empire Gas & Fuel Co.'s Martin No. 1 oil and gas test.
Elev. 3602 feet; top of salt 1565 feet (approx.); T.D. 2858 feet.
Mineralogy by J. J. Fahey.
Analyses by E. T. Erickson.
Remarks: Log corrected and reëxamined in part.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1626′2″–1629′5″	3′3″	Anhydrite and some polyhalite from 1626′2″ to 1626′11″, followed by 3″ of dark anhydrite with considerable magnesite. From 1627′2″ to 1629′5″ anhydrite with alternate bands of polyhalite.	40.4	6.18	15.45
		Interval of 96′1″.			
1725′6″–1736′6″	11′	Anhydrite with white and red halite to 1732′7″, followed by halite to 1735′. Remainder halite and anhydrite.	79.4	.87	1.09
1736′6″–1736′7″	1″	Magnesite and carnallite.	26.9	3.67	13.64
1736′7″–1737′	5″	Pinkish to gray shale with lenticles of anhydrite and magnesite. Less than 1.5% of K_2O.	------	------	------
		Interval of 55′.			
1792′–1795′10″	3′10″	Red sandy shale with halite and some polyhalite and carnallite.	46.6	2.89	6.20
1795′10″–1796′8″	10″	Red sandy shale with halite, anhydrite, carnallite, and green clay.	93.4	2.95	3.16
1796′8″–1800′	3′4″	Sandy shale with carnallite, some halite, and a few specks of anhydrite. Soft blue clay from 1797′9″ to 1798′4″.	65.8	4.73	7.20

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1800′–1805′	5′	Halite with included red sandy shale and some carnallite pits.	84.4	2.41	2.86
1805′–1809′	4′	Halite with a less prominent showing of carnallite pits.	92.6	1.83	1.97
1809′–1812′	3′	Halite with traces of carnallite, anhydrite, and polyhalite. A band of white anhydrite mixed with carnallite at bottom.	96.6	1.45	1.50
1812′–1816′	4′	Halite with scattered red and green shale inclusions and carnallite pits.	93.6	1.64	1.76
1816′–1823′8″	7′8″	Halite with a few large and small carnallite pits.	98.6	1.54	1.56
		Interval of 16′4″.			
1840′–1842′4″	2′4″	Halite with shale inclusions and a little polyhalite.	89.8	1.06	1.18
1842′4″–1845′	2′8″	Halite with red clay in last 1′4″.	83.0	.97	1.17
1845′–1847′3″	2′3″	Red shale with halite disseminated throughout.	61.0	.97	1.59
1847′3″–1854′6″	7′3″	Halite with fine brown shale inclusions.	89.2	.97	1.08
1854′6″–1857′2″	2′8″	Halite with very few clay inclusions.	96.0	.97	1.01
1857′2″–1857′8″	6″	Anhydrite, fine-grained, granular and greenish, locally stained salmon-colored to red with carnallite.	69.8	4.93	7.06
1857′8″–1858′7″	11″	Halite.	95.2	1.16	1.22
1858′7″–1859′1″	6″	Anhydrite, halite, and carnallite.	80.4	2.89	3.60
1859′1″–1862′	11″	Halite with a little carnallite at 1859′8″ to 1859′ 10″ and clay inclusions.	96.8	1.45	1.50
1862′–1865′3″	3′3″	Halite with red clay inclusions.	79.2	1.45	1.83
1865′3″–1868′6″	3′3″	Halite with some red clay.	96.0	.96	1.00
		Interval of 43′4″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1911′10″–1913′	1′2″	Halite, rose-tinted, grading to an increasing prominence of polyhalite inclusions.	96.0	2.12	2.20
1913′–1914′6″	1′6″	Polyhalite with some anhydrite and halite inclusions.	66.0	9.18	13.90
1914′6–1915″	6″	Halite with two ⅜″ bands of polyhalite.	97.6	3.38	3.46
1915′–1916′10″	1′10″	Halite with 3″ of polyhalite beginning at 1916′.	96.6	2.70	2.79
		Interval of 16′1″.			
1932′11″–1940′3″	7′4″	Halite with inclusions of brown shale and a scattering of carnallite pits and polyhalite blebs. 3″ band of red polyhalite at 1934′, and large carnallite cavities at 1938′.	97.0	1.45	1.50
1940′3″–1948′7″	8′4″	Halite intimately mixed with red clay. A small patch of carnallite at 1942′2″ and several small blebs between 1946′9″ and 1947′6″. The last 2″ is anhydrite.	89.4	1.06	1.19
		Interval of 37′7″.			
1986′2″–1987′6″	1′4″	3″ of halite, followed by 9″ of massive dark-red polyhalite with halite. At the base is brown and green shale grading to coarse clear salt.	66.4	6.75	10.17
		Interval of 37′6″.			
2025′–2026′4″	1′4″	Halite, with lenses and stringers of gray anhydrite and pink polyhalite.	95.0	2.80	2.95
		Interval of 14′4″.			
2040′8″–2041′7″	11″	Halite, anhydrite, and some polyhalite with a band of clay at the base.	79.2	1.06	1.34
		Interval of 5′5″.			
2047′–2047′11″	11″	The first 3″ is halite with a little polyhalite, followed by 6″ of massive polyhalite and 2″ of a	89.0	7.53	8.45

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		mixture of anhydrite, halite, and polyhalite.			
		Interval of 16′7″.			
2064′6″–2068′11″	4′5″	Anhydrite with some halite and a little polyhalite. Polyhalite increases toward the bottom.	60.8	1.25	2.06
2068′11″–2070′4″	1′5″	Polyhalite with anhydrite and halite.	58.0	5.69	9.82
2070′4″–2075′2″	4′10″	Anhydrite with a minor quantity of halite and polyhalite. Some gray clay between 2074′3″ and 2074′8″.	57.0	1.06	1.86
2075′2″–2082′	6′10″	Halite with bands of anhydrite and some polyhalite.	98.0	2.10	2.15
2082′–2084′6″	2′6″	Anhydrite with some polyhalite toward the bottom.	32.8	3.28	10.00
2084′6″–2086′	1′6″	Polyhalite changing to halite at 2085′10″.	75.2	9.75	12.95
		Interval of 101′11″.			
2187′11″–2192′8″	4′9″	Anhydrite with some halite to 2188′10″, followed by halite with increasing polyhalite to 2190′7″. Remainder anhydrite with polyhalite and some halite in the last 1′.	80.2	2.41	3.05
2192′8″–2193′7″	11″	Polyhalite. Last 2″ halite and green shale.	85.0	9.65	11.35
		Interval of 40′8″.			
2234′3″–2237′3″	3′	Two bands of red polyhalite separated by blebby salt from 2235′4″ to 2236′11″.	91.2	4.24	4.64
		Interval of 37′4″.			
2274′7″–2278′8″	4′1″	Halite. A thin seam of carnallite at 2275′1″. A little polyhalite and anhydrite in last 1′. Sylvite appears at 2278′4″ and is prominent in halite at 2278′7″.	97.4	1.93	1.98
2278′8″–2282′1″	3′5″	Intimate mixture of halite, sylvite, carnallite, leonite, and clay.	84.0	7.32	8.72

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2282′1″–2285′1″	3′	Halite with minor quantity of carnallite and clay throughout.	93.0	2.80	3.05
2285′1″–2289′	3′11″	Halite with a very little carnallite between 2286′ and 2287′1″.	97.4	2.60	2.67
2289′–2293′10″	4′10″	Halite with carnallite intimately mixed. Sylvite and clay are also present.	86.0	5.59	6.50
2293′10″–2299′9″	5′11″	Halite. Green clay in first 2′. Carnallite in small blebs throughout the core but the percentage is small. A few sylvite showings.	92.10	1.83	1.99
2299′9″–2305′2″	5′5″	Halite with large crystals of white sylvite, a scattering of carnallite, kieserite, and a few blebs of red polyhalite.	96.6	2.96	3.05
2305′2″–2307′1″	1′11″	First 8″ polyhalite with a minor quantity of halite, followed by 3″ of halite. From 2306′1″ to 2306′5″ polyhalite with a minor quantity of halite. The next 6″ anhydrite and polyhalite. The last 2″ polyhalite intermixed with gray clay.	73.0	8.68	11.90
2307′1″–2308′9″	1′8″	Halite with a few small blebs of sylvite.	91.6	3.28	3.58
		Interval of 34′.			
2342′9″–2344′	1′3″	Fine-grained pink polyhalite with irregular thin seams of green shale.	64.2	13.60	21.15
2344′–2345′6″	1′6″	Halite with red polyhalite blebs and a large crystal of red sylvite at 2344′. Less than 1.5% of K_2O.	-------	-------	-------
		Interval of 8′5″.			
2353′11″–2355′11″	2′	Halite. A minor quantity of sylvite in first 3″. Halite with small crystals of sylvite in the last 8″.	97.8	3.08	3.15
2355′–2355′11″	11″	An analysis of the lower 11″ of the previous section.	97.00	4.05	4.18

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2355′11″–2357′11″	2′	An intimate mixture of halite, sylvite, and polyhalite. A few seams of carnallite throughout the lower part.	93.4	15.25	16.32
2357′11″–2359′11″	2′	Halite and carnallite with green clay and red sylvite.	83.2	7.44	8.92
2359′11″–2361′8″	1′9″	Halite and carnallite with a minor quantity of green clay and a few blebs of sylvite.	......	..	.
2357′11″–2361′8″	3′9″	An analysis of the two previous sections.	87.0	6.27	7.22
2361′8″–2367′6″	5′10″	Halite. Inclusions of brown and green clay around 2362′ and 2363′6″. Sylvite and polyhalite at 2363′. Carnallite occurs in very small cavities at intervals throughout the core and is most abundant between 2364′4″ and 2364′10″.	90.2	2.70	2.95
2367′6″–2373′11″	6′5″	Halite. Concentration of white anhydrite in first 4″, with a minor quantity of kieserite, the whole intimately mixed with halite, which contains polyhalite blebs. Small carnallite pits are present from 2370′5″ to bottom and small white sylvite crystals. A 2″ seam of gray clay beginning at 2371′9″.	93.8	2.51	2.67
2373′11″–2376′5″	2′6″	An intimate mixture of carnallite and halite, with increasing halite toward the bottom.	90.2	7.13	7.90
2373′11″–2375′	1′1″	Sample for analysis from a part of above section. Core much dissolved. Carnallite with some halite.	79.0	9.35	11.83
2376′5″–2378′3″	1′10″	Halite with a considerable quantity of carnallite and a few polyhalite blebs. The carnallite diminishes toward the bottom.	90.6	4.05	4.48

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in sol ble salts
2378′3″–2385′	6′9″	Halite partly colored pink by traces of polyhalite and with inclusions of brown shale from 2379′ to 2380′. White and red sylvite and kieserite at 2384′6″ to 2385′.	97.8	2.12	2.16
2385′–2387′7″	2′7″	Red polyhalite containing a minor quantity of halite. There is a ½″ band of anhydrite at 2386′1″. A few crystals of sylvite at 2385′1″. Carnallite at 2385′8″ and 2386′ and a scattering of kieserite.	71.2	10.32	14.49
2387′7″–2398′	10′5″	Halite with scattered white sylvite crystals.	99.6	1.54	1.55
2398′–2401′8″	3′8″	Halite. A 1″ band of yellow waxy polyhalite at 2398′4″ A few blebs of carnallite mixed with clay from 2400′1″ to bottom.	75.6	2.12	2.80
2401′8″–2402′	4″	Dark-red to black clay. Contains some magnesite and small patches of carnallite.	95.0	3.38	3.56
2402′–2404′9″	2′9″	Halite with irregular inclusions of carnallite and black clay.	89.8	2.89	3.22
2404′9″–2405′	3″	Clear halite with a more prominent showing of carnallite.	97.6	3.18	3.26
2405′–2407′1″	2′1″	Halite with an irregular distribution of carnallite.	97.2	2.51	2.58
2407′1″–2414′11″	7′10″	Halite with a prominent showing of carnallite. Red and green shale inclusions.	87.2	9.12	10.45
2414′11″–2422′8″	7′9″	Halite with carnallite and a scattering of red and green clay. Carnallite is less prominent than in the preceding section.	82.8	3.47	4.20
2422′8″–2425′8″	3′	Halite containing minor quantities of carnallite and clay. Blebs of polyhalite appear around 2423′.	92.6	2.80	3.10

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2425′8″–2432′10″	7′2″	Halite with a minor quantity of carnallite throughout the run. There are a few patches of leonite in the first 10″ of the sample. Scattered inclusions of pink polyhalite. Red sylvite at 2428′ and at 2431′ with kieserite.	88.8	2.80	3.15
2432′10″–2434′5″	1′7″	First 4″ anhydrite containing small crystals of halite. Remainder halite with crystals and cavity linings of carnallite and sylvite.	94.4	1.83	1.94
2434′5″–2436′9″	2′4″	Halite. Large and many small inclusions of sylvite, which is, however, a minor constituent of the core. Carnallite in negligible amount.	95.4	7.41	7.78
2436′9″–2444′9″	8′	Halite with a scattering of various sized white and red sylvite crystals. Kieserite present.	96.8	.96	.99
2444′9″–2451′	6′3″	Halite containing a very small quantity of carnallite and sylvite in small scattered patches. The first 10″ contains much clay. The sylvite appears first at 2445′9″. Anhydrite and kieserite at 2450′10″.	91.6	2.12	2.31
2451′–2453′2″	2′2″	Halite intimately mixed with clay and carnallite. From 2451′9″ to 2452′ a 3″ seam of carnallite. A few small crystals of sylvite around 2451′6″. A show of red polyhalite at top.	90.4	3.18	3.53
2453′2″–2458′	4′10″	Halite with carnallite and red polyhalite blebs. Upper part carries 20 to 30% of brown clay inclusions. Sylvite is present in very small quantity about 2457′6″.	88.0	1.64	1.87
2458′–2461′9″	3′9″	Halite with 10% of included dark-brown clay.	79.2	2.56	3.23

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		There is a trace of polyhalite bleb inclusions.			
2461′9″–2469′7″	7′10″	Halite with varying amounts of shale inclusions and polyhalite blebs. The shale becomes as much as 50% of core at 2467′. A trace of sylvite throughout the run, but a few large crystals of red and white sylvite at 2468′6″. A show of kieserite.	92.8	2.89	3.12
		Interval of 20′6″.			
2490′1″–2491′	11″	3″ of polyhalite followed by halite with polyhalite blebs.	91.8	3.28	3.58
2491′–2492′5″	1′5″	Polyhalite containing inclusions of halite. A minor quantity of anhydrite in the first 2″.	69.7	7.52	10.70
2492′5″–2492′9″	4″	Anhydrite.	------	------	------
		Interval of 20′11″.			
2513′8″–2523′	9′4″	Halite with langbeinite, brown shale, and polyhalite blebs. The langbeinite occurs both in local concentrations at 2515′ to 2515′3″ and 2516′7″ to 2517′1″ and in scattered individual crystals.	97.2	4.24	4.36
	2′1″	An analysis of a 2′1″ section rich in langbeinite from 2515′ to 2517′1″.	99.7	9.16	9.18
	2′	An analysis of a 2″ section from 2521′ to 2523′.	93.8	2.12	2.26
2523′–2523′10″	10″	Langbeinite with a little clay, halite, and polyhalite.	89.4	11.41	12.80
2523′10″–2524′9″	11″	Langbeinite.	99.7	20.63	20.70
2524′9″–2532′2″	7′5″	Halite with an irregular scattering of langbeinite and polyhalite blebs. Some brown to black shale inclusions and thin bands.	99.6	4.64	4.65

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2524′9″–2526′9″	2′	An analysis of part of the above section. Halite with langbeinite and a little brown shale and polyhalite inclusion.	98.2	2.61	2.66
2532′2″–2539′4″	7′2″	Halite with langbeinite, a showing of leonite, red polyhalite blebs, and brown and green shale inclusions.	95.2	1.64	1.72
		Interval of 50′1″.			
2589′5″–2590′2″	9″	Polyhalite with a minor quantity of halite and clay.	84.6	9.06	10.70
		Interval of 19′2″.			
2609′4″–2609′6″	2″	Halite with a little included polyhalite.	-	-	----
2609′6″–2612′4″	2′10″	Polyhalite with a very minor amount of halite.	68.9	13.85	20.10
		Interval of 57′10″.			
2670′2″–2671′7″	1′5″	4″ of halite followed by polyhalite with fine inclusions of halite to 2671′2″. Remainder is halite containing a little polyhalite.	86.8	4.44	5.12
		Interval of 46′2″.			
2717′9″–2719′2″	1′5″	Pink to red polyhalite preceded by 2″ and followed by 1″ of halite.	80.8	9.08	11.25
		Interval of 21′7″.			
2740′9″–2742′7″	1′10″	5″ of halite followed by polyhalite to 2741′10″ to a 2″ clay layer. From 2742′ to 2742′7″ an intimate mixture of polyhalite, halite, and clay.	76.0	6.27	8.26
		Interval of 27′7″.			
2770′2″–2772′6″	2′4″	Halite with included red polyhalite to 2771′2″. From 2771′2″ to 2771′8″ anhydrite and polyhalite. The next 8″ is polyhalite, followed by 3″ of anhydrite and gray shale.	78.8	3.57	4.53
		Interval of 15′2″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2787′8″–2788′	4″	Halite with stringers of gray anhydrite and a few red polyhalite blebs.	------	- -	- -
2788′–2789′4″	1′4″	Polyhalite which grades downward into anhydrite. A 1″ band of anhydrite at 2788′4″.	58.1	9.97	17.16
2789′4″–2792′8″	3′4″	Graphic anhydrite with inclusions of halite. Anhydrite grades to polyhalite between 2791′1″ and 2792′2″.	49.8	3.28	6.58
2792′8″–2798′8″	6′	Graphic anhydrite with inclusions of halite and color of polyhalite. Anhydrite grades at base to a shale and clay.	51.6	1.06	2.05

Eighteenth Government Potash Test

Field notation: U. S. potash test, Texas No. 10.
Location: SW. ¼ sec. 5, block 28, public-school land, Loving County, Tex., on the Leeman ranch.
Elev. not available; top of salt 1205 feet; T.D. 1876 feet.
Mineralogy by Lee T. Richardson.
Analyses by E. T. Erickson.
Remarks: Log corrected and core reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1364′1″–1364′7″	6″	Anhydrite, upper half fine granular, lower part graphic, preceded by 2″ of halite. 1″ of pale-brown shale at base.	-------		-
		Interval of 6′3″.			
1370′10″–1371′10″	1′	Anhydrite, with banded inclusions of brown and green shale and halite. Polyhalite blebs in the halite.	---- -	--- -	-
		Interval of 6′.			
1377′10″–1378′2″	4″	Halite with polyhalite blebs, grades into a 3″ band of anhydrite, cemented brown shale with pale-gray to brownish anhydrite with blooms	--------		- - -

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		of kieserite. Reddish-brown shale and halite at base.			
		Interval of 26′3″.			
1404′5″–1404′10″	5″	First 1″ of core is halite, then 3″ of dull-gray fine-grained anhydrite on a 1″ brown shale base.	------	------	------
		Interval of 6′1″.			
1410′11″–1412′7″	1′8″	Halite with stringers of polyhalite and kieserite. Carnallite showings at 1412′2″.	------	------	------
1412′7″–1417′9″	5′2″	Halite with a varying amount of brown shale inclusions, polyhalite blebs, and kieserite. A 3″ band of red polyhalite with a little anhydrite at 1412′8″.	82.6	2.51	3.20
1417′9″–1423′10″	6′1″	Halite with a variable but minor amount of red and green shale, red polyhalite blebs, and carnallite. Prominent inclusions of carnallite at 1417′10″ to 1418′6″ and 1422′ to 1423′5″.	90.4	2.70	2.99
1423′10″–1424′9″	11″	Polyhalite and anhydrite, variable, with carnallite and kieserite stringers.	62.4	4.73	7.56
1424′9″–1426′10″	2′1″	Polyhalite with inclusions of anhydrite. Halite, carnallite, and kieserite also present.	75.2	7.62	10.13
1426′10″–1428′	1′2″	Anhydrite, massive and graphic, with halite, sylvite, kieserite and a show of carnallite.	59.6	5.02	8.42
1428′–1429′	1′	Anhydrite with a few fine magnesitic shale inclusions.	------	------	------
1429′–1438′	9′	Halite with variable amounts of brown shale inclusions, some polyhalite blebs, carnallite inclusions, and kieserite, especially at 1429′ to 1430′.	91.4	2.51	2.78

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1438′–1440′10″	2′10″	Halite. Small inclusions of kieserite, polyhalite blebs, and brown shale. Large crystals of white sylvite.	-------	-------	-------
1440′10″–1442′4″	1′6″	Anhydrite with prominent showing of red sylvite. Some carnallite, kieserite, and halite.	85.8	13.35	15.57
1442′4″–1451′	7′8″	Halite with scattered sylvite crystals. Inclusions of brown and green shale. Kieserite. Show of polyhalite and carnallite.	-------	-------	-------
1451′–1457′5″	6′5″	Halite with brown shale, sylvite, and kieserite inclusions.	-------	-------	-------
		Interval of 41′5″.			
1498′10″–1501′2″	2′4″	Halite with polyhalite and kieserite, except for last 4″, which is polyhalite.	90.2	2.90	3.21
		Interval of 3′9″.			
1504′11″–1506′5″	1′6″	Mixture of halite and polyhalite and kieserite. Polyhalite at 1506′ to 1506′5″, broken by a band of halite.	93.6	5.40	5.77
1506′5″–1506′11″	6″	Halite with bands of green and brown shale.	-------	-------	-------
		Interval of 54′2″.			
1561′1″–1571′5″	10′4″	Anhydrite except for polyhalite at 1562′8″ to 1562′ 11″ and 1571′2″ to 1571′ 3″ and halite at 1569′5″ to 1570′3″. 2″ of halite at base.	-------	-------	-------
		Interval of 68′7″.			
1640′–1640′10″	10″	Halite with bands of anhydrite, polyhalite, and kieserite to 1640′6″. Remainder polyhalite with a little halite and magnesitic shale.	-------	-------	-------
		Interval of 3′4″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1644′2″–1645′4″	1′2″	Halite with alternate 1″ and 2″ bands of red polyhalite.	----	----	----
		Interval of 4′6″.			
1649′10″–1650′7″	9″	Polyhalite with thin bands of halite. 2″ of halite at base.	90.0	9.65	10.70
		Interval of 15′11″.			
1666′6″–1667′	6″	3″ irregular band of anhydrite in halite with brown shale and polyhalite blebs.	----	----	----
		Interval of 18′.			
1685′–1686′10″	1′10″	3″ of polyhalite and 3″ more of polyhalite and anhydrite at top. Remainder anhydrite with halite.		----	----
1686′10″–1688′8″	1′10″	Polyhalite containing halite and anhydrite.	65.6	8.40	12.80
		Interval of 17′3″.			
1705′11″–1708′2″	2′3″	First 3″ mainly halite and blebby polyhalite. Next 4″ polyhalite. Remainder anhydrite containing some halite.	----	----	----
		Interval of 47′4″.			
1755′6″–1757′3″	1′9″	Anhydrite with some halite. Contains a very small show of polyhalite at 1756′10″.		----	----
		Interval of 77′10″.			
1835′1″–1835′7″	6″	Anhydrite with a very small quantity of included halite. 1″ of brownish shale at base.	----	----	----
		Interval of 8′7″.			
1844′2″–1844′9″	7″	First 2″ halite, followed by 2″ of polyhalite and halite. Remainder is anhydrite and halite.	----	----	----
		Interval of 26′1″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1870′10″–1873′	2′2″	First 3″ halite, then 3″ polyhalite, plus 3″ more of halite. At 1871′7″ to 1872′6″ a mixture of anhydrite and halite. Remainder contains 4″ of polyhalite, followed by 1½″ of gray shale and 1″ of polyhalite.	87.2	5.50	6.31
1873′–1875′5″	2′5″	Halite with inclusions of polyhalite blebs.	-------	----	-------
1875′5″–1879′	3′7″	Polyhalite with anhydrite and halite.	-------	----	----

Nineteenth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 9.
Location: SW. ¼ SW. ¼ sec. 31, T. 26 S., R. 35 E., Lea County, N. Mex.
Elev. 3210 feet (approx.); top of salt 1185 feet; T.D. 2011½ feet.
Mineralogy by J. J. Fahey.
Analyses by E. T. Erickson.
Remarks: Log corrected and core reëxamined.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1484′11″–1498′6″	13′7″	Halite with scattering of brown shale inclusions, polyhalite blebs and stringers, kieserite, and anhydrite. No identifiable carnallite found, although the presence of stains and cavities (1490′) is suggestive.	-------	----	----
		Interval of 31′4″.			
1529′10″–1533′6″	3′8″	Halite with stringers and inclusions of polyhalite and kieserite. Cavities in core at 1533′3″ suggestive of carnallite or sylvite.	-------	-------	-------
		Interval of 7′6″.			
1541′–1548′9″	7′9″	Halite. A complex core of polyhalite, anhydrite stringers, kieserite bands, and inclusions of sylvite and carnallite. A 5″ band of red polyhalite at 1543′ 7″.	-------	-------	-------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1548′9″–1559′5″	10′8″	Halite with a complex mixture of kieserite, carnallite, and sylvite. Scattered brown and green shale.	--------	--------	--------
1559′5″–1573′	13′7″	Halite with scattered inclusions. Carnallite, kieserite, polyhalite. Some shale and stringers of anhydrite and polyhalite.	--------	--------	--------
		Interval of 13′8″.			
1586′8″–1595′11″	9′3″	Halite with kieserite balls, polyhalite blebs. Some variable brown shale inclusions and prominent solution cavities.	--------	--------	--------
1595′11″–1608′	12′1″	Halite with brown shale and kieserite inclusions. Polyhalite from 1604′ to 1604′10″.	--------	--------	--------
1608′–1617′2″	9′2″	Halite with inclusions of carnallite, sylvite, kieserite, polyhalite bands, stringers, and blebs, and brown shale.	--------	--------	--------
		Interval of 44′7″.			
1661′9″–1672′1″	10′4″	Graphic anhydrite with inclusions of carnallite at 1667′ to 1669′ and 1670′ 6″ to 1671′9″. Polyhalite and halite also present.	--------	--------	--------
1672′1″–1672′10″	9″	Halite.	--------	--------	--------
		Interval of 43′9″.			
1716′7″–1721′5″	4′10″	Halite with anhydrite stringers to 1717′6″, followed by anhydrite with inclusions and bands of halite to 1720′1″. Halite with bands of magnesitic anhydrite to 1720′7″, followed by red polyhalite to 1721′3″ and 2″ of green shale.	--------	--------	--------
1721′5″–1732′2″	10′9″	Halite. At 1724′7″ to 1725′3″ a complex band of polyhalite, anhydrite, halite, and kieserite, and	--------	--------	--------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		at 1731′6″ to 1732′2″ another of polyhalite in halite with anhydrite and gray shale. Shale inclusions and solution vugs.			
1732′2″–1744′1″	11′11″	Halite with variable brown shale inclusions, solution cavities, polyhalite blebs. Kieserite balls. Red carnallite at 1735′11″ and 1742′2″.	------	------	------
1744′1″–1746′10″	2′9″	Complex halite core with anhydrite, polyhalite, kieserite, and carnallite associates.	------	------	------
1746′10″–1751′6″	4′8″	Halite with kieserite balls, polyhalite blebs.	------	------	------
1751′6″–1753′6″	2′	Halite with thin bands of polyhalite and kieserite. Polyhalite and kieserite at 1753′1″ to 1753′6″.	------	------	------
1753′6″–1757′3″	3′9″	Halite with polyhalite blebs, sylvite and kieserite.	------	------	------
		Interval of 30′11″.			
1788′2″–1792′4″	4′2″	Polyhalite and anhydrite with inclusions of halite and kieserite. Essentially polyhalite from 1789′ to 1790′4″; then anhydrite to 1791′3″ and polyhalite to 1791′10″. A few carnallite inclusions in the remaining 4″ of halite.	75.8	6.98	9.20
		Interval of 148′6″.			
1940′10″–1942′	1′2″	Polyhalite with halite and inclusions of kieserite.	89.4	8.87	9.93
		Interval of 8′8″.			
1950′8″–1951′9″	1′1″	Polyhalite with halite and shale.	76.6	7.42	9.70
		Interval of 26′.			
1977′9″–1978′3″	6″	Polyhalite with halite.	90.0	9.40	10.42
		Interval of 7′11″.			
1986′2″–1989′1″	2′11″	White polyhalite, anhydrite and halite.	74.8	7.76	10.39
		Interval of 10′3″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1999′4″–2002′	2′8″	Anhydrite, polyhalite with halite. A 5″ band of red polyhalite beginning at 1999′10″.	53.7	3.48	6.48
		Interval of 9′4.			
2011′4″–2013′4″	2′	Halite with irregular bands of polyhalite. Anhydrite at base.	89.8	3.42	3.81

Twentieth Government Potash Test

Field notation: U. S. potash test, New Mexico No. 10.
Location: NW. ¼ SW. ¼ sec. 3, T. 23 S., R. 32 E., Lea County, N. Mex.
Elev. 3650 feet (approx.); top of salt 1195 feet; T.D. 2302 feet.
Mineralogy by F. C. Calkins.
Analyses by E. T. Erickson.
Remarks: Log corrected and core reëxamined except for one short section.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1372′–1383′	11′	Massive and graphic anhydrite with prominent halite bands at 1379′11″ to 1380′9″.	------	------	------
		Interval of 16′10″.			
1499′10″–1500′7″	9″	Red polyhalite with a little halite and brown shale.	------	------	------
		Interval of 59′11″.			
1560′6″–1561′3″	9″	Red polyhalite with seams and fine inclusions of halite.	------	------	------
		Interval of 8′3″.			
1569′6″–1570′6″	1′	Red polyhalite with 50% halite bands and green shale at base.	------	------	------
		Interval of 31′11″.			
1602′5″–1602′10″	5″	Red polyhalite with halite inclusions.	------	------	------
		Interval of 13′4″.			
1615′2″–1615′9″	7″	Red polyhalite with some fine banded inclusions of halite.	------	------	------
		Interval of 40′.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1655′9″–1658′	2′3″	Upper half halite with polyhalite bands. Lower half polyhalite with halite inclusions and a clay base.	----	----	----
		Interval of 35′6″.			
1693′6″–1695′	1′6″	Anhydrite with a shale base and inclusions of halite. Upper 4″ polyhalite with halite and anhydrite.	----	----	----
		Interval of 13′8″.			
1708′8″–1710′	1′4″	3″ of halite followed by 8″ of polyhalite and included halite. Remainder graphic anhydrite.	86.6	5.40	6.23
		Interval of 18′2″.			
1728′2″–1728′7″	5″	Red polyhalite with fine inclusions of halite.	----	----	----
		Interval of 26′10″.			
1755′5″–1756′8″	1′3″	Polyhalite with anhydrite, halite and clay.	----	----	----
		Interval of 16′2″.			
1772′10″–1774′6″	1′8″	Polyhalite with thin bands and inclusions of halite and brown shale.	87.9	9.70	10.32
		Interval of 8′6″.			
1783′–1783′10″	10″	A thin band of polyhalite and fine granular halite with interlacing polyhalite to 1783′3″, followed by a massive layer of red polyhalite. Remainder gray graphic anhydrite.	----	----	----
		Interval of 47′6″.			
1831′4″–1833′7″	2′3″	Massive red polyhalite with only a very little fine halite inclusion at 1831′7″ and anhydrite and a shaly base.	63.8	12.93	20.25
		Interval of 57′7″.			
1891′2″–1891′7″	5″	Red polyhalite.	----	----	----
		Interval of 18′9″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1910′4″–1912′1″	1′9″	From 1910′4″ to 1911′ a mixture of polyhalite and halite. Remainder polyhalite with minor inclusions of halite.	85.6	9.02	10.65
		Interval of 30′6″.			
1942′7″–1944′6″	1′11″	Halite with polyhalite stringers to 1943′4″, followed by graphic anhydrite with halite and polyhalite.	------	--------	-------
		Interval of 2′4″.			
1946′10″–1950′2″	3′4″	Halite with bands of polyhalite to 1948′2″. Polyhalite with a little shale and halite to 1949′8″. Remainder with stringers and blebs of polyhalite.	79.9	6.62	8.27
		Interval of 9′7″.			
1959′9″–1963′5″	3′8″	Anhydrite to 1961′2″. Polyhalite to 1962′3″. Remainder graphic anhydrite, polyhalite with halite, and shale.	------	--------	-------
		Interval of 8′4″.			
1971′9–1972′10″	1′1″	Halite to 1972′3″. Remainder polyhalite with halite inclusions.	------	--------	-------
		Interval of 5′.			
1977′10″–1978′2″	4″	Polyhalite with bands of fine graphic halite.	------	--------	-------
		Interval of 9′4″.			
1987′6″–1987′10″	4″	Irregular band of polyhalite in halite.	------	--------	-------
		Interval of 8′7″.			
1996′5″–1998′11″	2′6″	Polyhalite with numerous bands of halite and some anhydrite.	64.8	6.08	7.17
		Interval of 9′4″.			
2008′3″–2010′7″	2′4″	Halite with thin bands of polyhalite to 2009′1″. Remainder polyhalite with a shale base.	84.4	9.17	10.85
		Interval of 77′1″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2087′8″–2090′8″	3′	Halite to 2088′9″ with a band of polyhalite at 2088′. Remainder polyhalite.	83.6	9.80	11.70
		Interval of 23′4″.			
2114′–2115′3″	1′3″	Polyhalite with halite bands and inclusions.	-------	-------	-------
		Interval of 4′11″.			
2120′2″–2120′6″	4″	Polyhalite.	-------	-------	-------
		Interval of 14′11″.			
2135′5″–2138′6″	3′1″	Halite with polyhalite stringers to 2136′9″. Remainder polyhalite with a little halite and shale.	91.7	7.43	8.10
		Interval of 39′5″.			
2177′11″–2186′2″	8′3″	Halite followed by polyhalite from 2178′ to 2179′ 10″. Halite and shale to 2185′3″. Polyhalite to base.	94.6	5.95	6.29
		Interval of 31′10″.			
2218′–2233′1″	15′1″	Anhydrite, essentially, variably banded and graphic, with partial alteration to polyhalite locally. Included halite. Last 5′ shaly and magnesitic.	-------	-------	-------
2221′6″–2226′	4′6″	Analysis of part of above section.	41.8	4.93	11.80
		Interval of 49′3″.			
2282′4″–2302′11″	20′7″	Anhydrite, coarse and fine, graphic, partly altered to white and red polyhalite with inclusions and bands of halite.	-------	-------	-------
	3′	Analysis of a section from 2284′ to 2287′.	65.9	13.08	19.83
	4′3″	Analysis of a section from 2298′8″ to 2302′11″.	36.4	9.55	16.90

Twenty-first Government Potash Test

Field notation: U. S. potash test, New Mexico No. 11.
Location: NE. ¼ SE. ¼ sec. 11, T. 21 S., R. 34 E., Lea County, N. Mex.
Elev. not available; top of salt 2079 feet (approx.): T.D. 3003 feet.
Mineralogy by R. K. Bailey.
Analyses by R. K. Bailey.
Remarks: Log corrected but reëxamination incomplete.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2096′–2110′6″	14′6″	Anhydrite, graphic; bands and inclusions of halite. Local faint alteration to polyhalite. Essentially halite from 2105′3″ to 2107′9″.	----	----	----
	5′9″	Analysis of a section from 2099′6″ to 2105′3″.	45.90	.44	.96
	1′8″	Analysis of a section from 2107′10″ to 2109′6″.	44.70	.61	1.37
		Interval of 25′7″.			
2136′1″–2136′10″	9″	Anhydrite, buff to red, with halite and sandy shale inclusions.		----	----
		Interval of 87′7″.			
2224′5″–2263′6″	39′1″	Halite, with a scattering of brown-green shale inclusions, carnallite, polyhalite blebs, kieserite, anhydrite. More prominent carnallite showings at 2239′ to 2244′, 2254′, and 2259′ to 2262′.	----	----	
		Interval of 40′4″.			
2303′10″–2312′	8′2″	Halite, with bands of red polyhalite, anhydrite, gray and brown shale inclusions, carnallite, kieserite. Prominent carnallite showing at 2309′ to 2310′6″.		----	----
		Interval of 52′1″.			
2364′1″–2366′2″	2′1″	Halite, with polyhalite blebs and two bands of gray anhydrite at 2365′. Scattered small carnallite crystals and kieserite.		----	----
		Interval of 26′10″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2393′–2395′3″	2′3″	Polyhalite, massive and banded with halite and gray graphic anhydrite.	----	-	–
		Interval of 9′4″.			
2404′7″–2405′11″	1′4″	Polyhalite with a fine inclusion of poikilitic halite and some anhydrite.	--------	--------	--------
		Interval of 6′8″.			
2412′7″–2413′2″	7″	Polyhalite with a ⅛″ gray shale base.	-------	-------	-------
		Interval of 22′7″.			
2435′9″–2440′4″	4′7″	Anhydrite, graphic and banded with poikilitic halite inclusions. Crystals of red carnallite at 2439′.	44.80	.61	1.56
2440′4″–2443′10″	3′6″	Anhydrite, gray, coarse, graphic, with carnallite.	42.50	2.91	6.84
2443′10″–2447′1″	3′3″	Anhydrite, light brown to gray, with halite, carnallite, and gray shale.	———	———	———
	2′10″	Analysis of a section from 2443′10″ to 2446′8″.	28.30	1.06	3.75
		Interval of 4′3″.			
2451′4″–2454′1″	2′9″	Polyhalite, graphic anhydrite, halite, kieserite, and gray shale.	------	--------	- -
		Interval of 2′3″.			
2456′4″–2457′4″	1′	Anhydrite, polyhalite, shaly anhydrite, and a little halite.	--------	------	--------
		Interval of 25′6″.			
2482′10″–2483′3″	5″	Red polyhalite with a little halite and gray shale.	-------	-------	-------
		Interval of 23′8″.			
2506′11″–2508′	1′1″	Polyhalite with a little included halite and a 3″ halite band at 2507′.	-------	--------	-------
		Interval of 8′11″.			
2516′11″–2517′7″	8″	Polyhalite with fine inclusions and stringers of halite.	--------	--------	-------
		Interval of 20′11″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2538′6″–2539′5″	11″	Polyhalite with a little fine-grained halite inclusion.	------	------	------
		Interval of 9′3″.			
2548′8″–2550′4″	1′8″	Polyhalite, dense, buff to dark red.	88.90	14.91	16.80
2550′4″–2552′8″	2′4″	Halite, fine-grained, with fine lacy polyhalite diffused throughout.	------	------	------
2552′8″–2557′8″	5′	Polyhalite, buff to dark red, dense and graphic. Minor percentage of halite except at 2556′9″ to 2557′. Remainder polyhalite grading into anhydrite.	58.80	8.89	15.10
2557′8″–2559′9″	2′1″	Anhydrite and polyhalite, fine banded with ⅛″ to ¼″ seams of magnesitic clay.	37.80	5.79	15.30
		Interval of 54′2″.			
2613′11″–2614′4″	5″	Red polyhalite with halite inclusion.	------	------	------
		Interval of 33′2″.			
2647′6″–2648′11″	1′5″	Polyhalite, red, in massive, graphic, and poikilitic textures with included halite and a green clay base.	76.70	12.60	16.42
		Interval of 37′.			
2685′11″–2687′1″	1′2″	Polyhalite with fine graphic bands of halite and a gray shale base.	------	------	------
		Interval of 27′11″.			
2715′–2726′5″	11′5″	Halite with scattered brown shale and a little polyhalite inclusion. Fine showings of kainite, kieserite, loeweite, bloedite. A more prominent display of langbeinite at 2721′ to 2725′.	------	------	------
2726′5″–2728′	1′7″	Polyhalite with a little disseminated halite and a 2″ halite stratum at 2726′7″.	75.80	11.92	15.73

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2728′–2734′11″	5′11″	Halite with polyhalite bleb inclusions and kieserite.	--------	--------	--------
2734′11″–2735′3″	4″	Pink polyhalite and graphic halite inclusions.	--------	--------	--------
2735′3″–2741′7″	6′4″	Halite with brown shale and polyhalite inclusions and kainite. Leonite and langbeinite from 2739′6″ to 2741′.	--------	--------	--------
	2′	Analysis of a section from 2739′ to 2741′.	95.40	4.44	4.66
		Interval of 14′11″.			
2756′6″–2759′10″	3′4″	Halite and anhydrite with a 6″ polyhalite band at 2757′9″.	73.00	4.01	5.48
2759′10″–2762′6″	2′8″	Pink polyhalite and a little anhydrite at base.	63.80	13.42	21.05
2762′6″–2763′1″	7″	Anhydrite.	--------	--------	--------
2763′1″–2765′8″	2′7″	Red polyhalite with halite inclusions, gray anhydrite, and magnesitic shale.	76.30	12.20	16.05
2765′8″–2769′	3′4″	Halite with red polyhalite bands, gray anhydrite, and gray-green shale.	--------	--------	--------
		Interval of 18′3″.			
2787′3″–2787′7″	4″	Pink polyhalite.	--------	--------	--------
		Interval of 26′4″.			
2813′11″–2816′7″	2′8″	Red polyhalite with halite inclusions above 2814′6″.	61.10	12.20	19.95
2816′7″–2821′6″	4′11″	Gray anhydrite with inclusions of halite.	20.20	.68	2.87
2821′6″–2824′6″	3′	Gray shale with inclusions of anhydrite and polyhalite.	--------	--------	--------
		Interval of 25′10″.			
2850′4″–2850′9″	5″	Polyhalite with inclusions of halite.	--------	--------	--------
		Interval of 85′4″.			
2936′1″–2937′9″	1′8″	Polyhalite with halite inclusions and gray shaly base.	--------	--------	--------
		Interval of 24′1″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
2961′10″–2962′10″	1′	Red polyhalite with a fine inclusion of halite.	------	-----	--------
		Interval of 36′8″.			
2999′6″–3004′	4′6″	Halite with stringers of polyhalite to 3002′8″. Remainder red polyhalite.	----	----	----

Twenty-second Government Potash Test

Field notation: U. S. potash test, New Mexico No. 12.
Location: SE. ¼ SE. ¼ sec. 26, T. 23 S., R. 30 E., Eddy County, N. Mex.
Elev. not available; top of salt 609 feet; T.D. 1724 feet.
Mineralogy by F. C. Calkins.
Analyses by E. T. Erickson.
Remarks: Log corrected and core reëxamination completed. (The word cryptic as used in the table means that the mineral described is not readily apparent but may be detected by analysis or other methods.)

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
638′–640′	2′	Red polyhalite with inclusions, bands, and lenses of halite.	86.0	10.65	12.39
		Interval of 42′.			
682′–684′7″	2′7″	Dark red polyhalite with scattered inclusions of halite, especially in the upper 3″.	67.6	12.63	18.69
684′7″–685′7″	1′	Blebby halite with bands of polyhalite.	--------	--------	----
		Interval of 10′8″.			
696′3″–697′4″	1′1″	Blebby halite with a 2″ layer of red polyhalite at 696′8″.	95.6	3.66	3.83
		Interval of 27′9″.			
725′1″–725′11″	10″	Polyhalite with a little halite as inclusions and thin bands.	-------	--------	-------
		Interval of 41′8″.			
767′7″–768′9″	1′2″	Dense pale-grayish anhydrite with some halite and a 2″ pale-gray magnesitic clay base.	--------	--------	--------
		Interval of 21′6″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
790′3″–790′8″	5″	Dense red polyhalite.	--------	--------	--------
		Interval of 36′6″.			
827′2″–827′10″	8″	Red polyhalite with a 2″ irregular layer of halite through the center.	--------	--------	--------
		Interval of 26′7″.			
854′5″–855′9″	1′4″	Red polyhalite with a fine distribution of halite and a 3″ halite layer at 855′3″. Gray-green shale base.	--------	--------	--------
		Interval of 22′7″.			
878′4″–879′11″	1′7″	Halite with prominent inclusions of polyhalite.	--------	--------	--------
879′11″–881′9″	1′10″	Anhydrite and halite.	--------	--------	--------
881′9″–885′3″	3′6″	Polyhalite, graphic and banded, anhydrite, and halite.	62.2	4.43	7.12
885′3″–885′10″	7″	Anhydrite and brown-green shale (magnesitic).	--------	--------	--------
885′10″–892′6″	6′8″	Halite with blebs and stringers of polyhalite to 890′10″. Remainder olive-gray anhydrite with fine halite inclusion.	--------	--------	--------
892′6″–894′6″	2′	Halite with prominent stringers of red polyhalite.	98.8	2.41	2.44
		Interval of 45′11″.			
940′5″–941′8″	1′3″	Red polyhalite with wavy bands of included halite.	84.5	8.23	9.74
		Interval of 8′8″.			
950′4″–950′8″	4″	Red polyhalite.	--------	--------	--------
		Interval of 17′5″.			
968′1″–969′7″	1′6″	Red polyhalite with an irregular mixture of pale-gray anhydrite and halite. 2″ of pale-gray shale at base.	63.4	8.97	14.15
		Interval of 22′2″.			
991′9″–992′1″	4″	Red polyhalite, banded.	--------	--------	--------
		Interval of 7′8″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
999′9″–1001′7″	1′10″	Red polyhalite, gray anhydrite, and halite.	70.0	5.00	7.15
		Interval of 9′2″.			
1010′9″–1011′7″	10″	Red polyhalite for 3″, followed by gray-green shaly anhydrite and shale; halite inclusions.	-------	-------	-------
		Interval of 7′11″.			
1019′6″–1021′1″	1′7″	Anhydrite intimately intermixed with approximately an equal proportion of halite.	-------	-------	-------
1021′1″–1023′10″	2′9″	Red polyhalite, massive and graphic, with halite inclusions and bands and gradations to anhydrite. A 2″ gray-green magnesitic clay base.	70.9	6.75	9.52
		Interval of 13′11″.			
1037′9″–1038′	3″	Red polyhalite with a 10% scattering of fine halite.	-------	-------	-------
		Interval of 10′7″.			
1048′7″–1048′10″	3″	Dark-red polyhalite.	-------	-------	-------
		Interval of 9′10″.			
1058′8″–1062′1″	3′5″	Red polyhalite with halite and gray anhydrite.	72.8	9.83	13.50
1062′1″–1063′8″	1′7″	Anhydrite with halite and polyhalite.	-------	-------	-------
		Interval of 4′.			
1067′8″–1069′11″	2′3″	Red polyhalite with some included halite (cryptic anhydrite).	75.2	6.90	9.16
		Interval of 26′8″.			
1096′7″–1097′7″	1′	Halite with stringers of red polyhalite grading into a 3″ layer of massive polyhalite.	96.0	4.20	4.38
		Interval of 22′5″.			
1120′–1120′10″	10″	Halite with irregular layers, lenses, and blebs of deep-red polyhalite.	-------	-------	-------
		Interval of 31′2″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1152′–1154′1″	2′1″	Red polyhalite with halite and a little shale inclusion.	73.3	13.62	18.60
		Interval of 18′5″.			
1172′6″–1173′3″	9″	Polyhalite of buff color and fine texture, grading downward into halite.	....	....	....
1173′3″–1175′3″	2′	Halite with polyhalite inclusions and gray clay.	....	....	....
1175′3″–1177′9″	2′6″	Polyhalite, buff, with a 2″ gray shale break at 1176′6″ and a minor showing of halite.	75.8	11.65	15.35
1177′9″–1179′7″	1′10″	Polyhalite of a dull-buff color with cryptic anhydrite. Upper 6″ of section contains irregular bands of halite, anhydrite, and magnesitic clay.	75.6	9.98	13.20
1179′7″–1182′11″	3′4″	Buff polyhalite, similar to above, with a halite layer at 1180′9″ to 1182′1″, and gray-green clay.	97.0	5.73	5.90
		Interval of 16′10″.			
1209′9″–1211′2″	1′5″	Halite with seams and blebs of red polyhalite.	....	....	....
1211′2″–1212′	10″	Light gray-green wavy magnesitic shale with included polyhalite and halite.	....	....	....
		Interval of 3′.			
1215′–1218′6″	3′6″	Halite with blebs of polyhalite and scattering of red sylvite crystals.	97.4	.77	.89
1218′6″–1221′1″	2′7″	Halite with polyhalite blebs, green shale inclusions (magnesitic), red sylvite, kainite, leonite, and a trace of blue halite.	....	....	....
	9″	Analysis of a section from 1218′6″ to 1219′3″.	91.2	21.90	24.00
	1′10″	Analysis of a section from 1219′3″ to 1221′1″.	84.4	14.80	17.55

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1221′1″–1222′3″	1′2″	Halite with leonite, sylvite, variegated clay inclusions, and polyhalite.	86.2	15.35	17.80
1222′3″–1224′3″	2′	Halite with included clay, sylvite, and blebs of polyhalite.	88.3	3.07	3.48
1224′3″–1232′10″	8′7″	Halite with a scattering of brown clay inclusions, polyhalite and sylvite.	98.8	3.52	3.56
1232′10″–1235′11″	3′1″	Halite with polyhalite blebs and stringers increasing with depth and a show of sylvite and blue halite at top.	------	------	------
1235′11″–1236′11″	1′	Red polyhalite faintly banded with stringers and inclusions of halite.	------	------	------
		Interval of 17′1″.			
1254′–1255′5″	1′5″	Red polyhalite with irregular inclusions of gray anhydrite and halite. Greenish-gray clay base.	66.8	10.80	16.17
		Interval of 10′6″.			
1265′11″–1268′2″	2′3″	Blebby halite with bands of polyhalite grading to buff polyhalite at 1266′ 10″. Polyhalite, wavy with magnesitic gray shale films and halite inclusions.	88.7	6.75	7.60
		Interval of 39′10″.			
1308′–1310′11″	2′11″	Banded gray anhydrite; changes to a more massive red polyhalite at 1308′3″, which in turn becomes shaly and changes to halite at 1310′2″.	66.7	10.70	16.05
		Interval of 49′9″.			
1360′8″–1363′	2′4″	Variegated pinkish to pale-grayish polyhalite and anhydrite with halite stringers and layers. 3″ of halite at 1361′10″.	------	------	------
1363′–1366′	3′	Massive pale greenish-gray polyhalite with stringers of halite.	75.0	11.60	13.49

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1366′–1367′11″	1′11″	Gray graphic anhydrite and halite. Some cryptic polyhalite at top.	--	--	--
1366′–1367′1″	1′1″	Analysis of part of above section.	51.6	2.28	4.42
		Interval of 5′10″.			
1373′9″–1375′2″	1′5″	Buff polyhalite with an admixture of anhydrite and inclusions, some graphic, of halite.	53.4	6.17	11.55
1375′2″–1381′8″	6′6″	Anhydrite, gray, massive, fine graphic, and banded, grading into shale.	--	--	--
1381′8″–1382′11″	1′3″	Gray shale with a very fine inclusion of halite.	--	--	--
1382′11″–1383′7″	8″	Porcelaneous pearl-gray magnesitic anhydrite and polyhalite. Red halite and pale olive-green shale at last 1″.	--	--	--
		Interval of 7′2″.			
1390′9″–1392′1″	1′4″	Halite with polyhalite blebs, black clay inclusions and kieserite.	--	--	--
		Interval of 17′6″.			
1409′7″–1410′11″	1′4″	Halite with green shale layer and brown shale inclusion; salmon-red polyhalite layers and blebs; showing of red sylvite and langbeinite.	--	--	--
1410′11″–1416′6″	5′7″	Halite with a prominent inclusion of variegated reddish-brown and green shale. Langbeinite prominent at 1413′, 1414′, and 1415′. Kainite at 1412′3″. Leonite, sylvite, anhydrite, kieserite, and lueneburgite.	8.66	3.43	3.96
1416′6″–1422′9″	6′3″	Halite with but little brown shale and polyhalite blebs. Langbeinite and sylvite distributed. Kainite, leonite, kieserite. Blue halite.	94.0	3.78	4.03

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1422′9″–1423′2″	5″	Bright-red polyhalite with included halite in the upper 1½″.	....	.....	....
1423′2″–1423′10″	8″	Upper 3″ blue shale, followed by halite with langbeinite, kainite, and leonite.	....	....	....
1423′10″–1439′1″	15′3″	Halite with prominent showings of brown-gray shale and red polyhalite inclusions in the first 3′; the second 3′ relatively clear halite. The remainder carries prominent fine scattering of sylvite and langbeinite. Leonite, kainite. Blue halite also present.	97.7	3.08	3.15
		Interval of 9′4″.			
1448′5″–1449′6″	1′1″	Halite with crystals of aphthitalite.	....	....	....
		Interval of 13′1″.			
1462′7″–1463′1″	6″	Pink polyhalite with a little halite and gray shale inclusion.	....	.....	....
		Interval of 36′8″.			
1499′9″–1500′8″	11″	Red polyhalite in irregular masses included by halite with polyhalite blebs and a thin layer of gray-green shale at 1500′8″.	90.8	2.94	3.24
1500′8″–1502′10″	2′2″	Red polyhalite with inclusions of halite and pale-gray shale.	66.8	12.43	18.61
		Interval of 33′11″.			
1536′9″–1538′6″	1′9″	Irregularly layered polyhalite, halite, and anhydrite.	75.2	4.53	6.02
		Interval of 26′11″.			
1565′5″–1567′4″	1′11″	Polyhalite, dark red, massive, with dark-gray shale films and an inclusion of minute halite crystals.	68.6	11.48	16.72
		Interval of 11′9″.			

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
1579'1"–1579'9"	8"	Red polyhalite irregularly inter-layered with halite and fine gray clay.	----	----	----
		Interval of 50'10".			
1630'7"–1631'3"	8"	Red polyhalite, massive; grades upward at 1630' 10" into halite and polyhalite.	----	----	----
		Interval of 19'.			
1650'3"–1651'6"	1'3"	Polyhalite, coarse texture, massive and glassy, with microscopic halite included.	----	----	----
		Interval of 49'8".			
1701'2"–1702'2"	1'	Alternate layers of halite and red polyhalite.	83.4	7.18	8.61
1702'2"–1703'10"	1'8"	Polyhalite, red, massive, coarse-grained, with anhydrite appearing near 1703'3" and euhedral quartz crystals at 1703'6".	57.6	10.73	18.65

Twenty-third Government Potash Test

Field notation: U. S. potash test, New Mexico No. 13.
Location: NW. ¼ NW. ¼ sec. 35, T. 20 S., R. 29 E., Eddy County, N. Mex.
Elev. 3306 feet; top of salt 512 feet (approx.); T.D. 904 feet.
Mineralogy by F. C. Calkins.
Analyses by Lee T. Richardson.
Remarks: Log corrected and core reëxamination completed.

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
517'–526'8"	9'8"	Halite with a scattering of brown clay and polyhalite blebs. Carnallite at 517' to 518'. Sylvite scattered through the core. Some very fine diffused anhydrite at 519' and blue halite at 523'.	----	----	----
526'8"–528'4"	1'8"	Milky halite with red polyhalite blebs grading into dense fine-grained polyhalite and anhydrite at 527'3". Polyhalite clear and pinkish; anhydrite white chalky to glassy.	----	----	----

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
528′4″–529′6″	1′2″	Halite with polyhalite blebs and green clay. Carnallite and blue halite present.	......	......	......
		Interval of 17′9″.			
547′3″–569′8″	22′5″	Halite with but a minor showing of brown and greenish-gray clay. Polyhalite blebs inconspicuous. Portions of core shattered into "checkers" and made cellular by excessive solution. Remnants of sylvite and carnallite. Kieserite and blue halite.	......	......	......
569′8″–572′3″	2′7″	Halite with brown-green shale increasing to 40% at 571′10″ to 572′3″. Dark-red carnallite at 570′ and red sylvite prominent at 571′3 to 571′9″. Kieserite.	91.7	2.38	2.60
		Interval of 21′1″.			
593′4″–593′10″	6″	Polyhalite, dense, clear, rose-colored, at 593′5″ to 593′8″. Bounding halite contains sylvite and blue halite.	......	......	......
		Interval of 16′5″.			
610′3″–612′6″	2′3″	Polyhalite, pale-pinkish and greenish-gray anhydrite (core shattered) with 2″ of halite at 611′ 5″. Above 610′9″ halite with inclusions of polyhalite.	......	......	......
612′6″–623′1″	10′7″	Halite with blebs of brownish to whitish polyhalite and anhydrite. White and red sylvite scattered through core with a concentration of large crystals at 616′ to 617′.	99.0	1.43	1.44
	1′	Analysis of a section from 616′ to 617′.	99.7	4.54	4.55
623′1″–629′	5′11″	Red polyhalite, granular and becoming grayish	71.0	11.52	16.20

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		where anhydrite predominates. Halite inclusions, more prominent in the first 1′.			
629′–633′	4′	Mottled anhydrite, faintly banded with red halite stringers. Red sylvite ⅛″ to ¼″ crystals, in anhydrite at 631′.	———	———	———
633′–634′6″	1′6″	Anhydrite, shaly, cross-bedded, grading to dull mouse-gray shale with nodules of pink polyhalite. Red halite and a little red sylvite at 633′6″.	———	———	———
634′6″–643′	8′6″	Halite, clear, with faint whitish to pinkish polyhalite inclusions, scattered red crystals of sylvite (carnallite?).	99.1	1.55	1.56
643′–644′10″	1′10″	Halite with 25% of green shale and some brown shale inclusions. Polyhalite blebs. Few sylvite crystals at 644′6″.	98.7	1.61	1.63
644′10″–645′1″	3″	Dark-gray shale.	———	———	———
645′1″–648′	2′11″	Halite with 40% of brown-green shale inclusions and scattered red sylvite.	89.2	3.47	3.90
648′–650′2″	2′2″	Halite, few shale inclusions and polyhalite blebs; bright-red sylvite crystals, especially at 649′9″.	97.8	1.77	1.81
650′2″–650′10″	8″	Halite and brown shale.	———	———	———
650′10″–655′6″	4′8″	Halite with but few shale inclusions except a 6″ gray-green layer at 653′ 6″. Red and milky-white sylvite scattered throughout.	96.4	2.14	2.22
655′6″–661′	5′6″	Halite with black shale becoming very prominent at base. Sylvite scattered throughout. White sylvite with green shale at 655′ 9″. Red sylvite abundant at 656′3″ to 657′6″.	97.7	7.42	7.60

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
661′–668′6″	7′6″	Halite. Black shale, red and white sylvite, polyhalite stringers, anhydrite balls. Blue halite and kieserite dispersed in minor amounts.	97.8	5.67	5.92
668′6″–671′6″	3′	Halite with a little green shale, red sylvite, kieserite (carnallite?).	------	------	------
671′6″–675′10″	4′4″	Halite. Red sylvite, kieserite. Blue halite in minor amounts.	99.5	2.18	2.19
675′10″–677′3″	1′5″	Polyhalite, anhydrite, and halite, with small crystals of red sylvite.	------	------	------
677′3″–681′	3′9″	Halite with a sprinkling of red sylvite, green shale, disseminated granular anhydrite and polyhalite. Blue halite. Carnallite and kieserite.	98.1	2.27	2.32
681′–682′	1′	Halite. 3″ of 60% reddish-brown clay at 681′1″ and fine-grained halite and carnallite.	93.2	2.57	2.76
682′–683′	1′	Halite, brown shale, and a few polyhalite blebs.	99.2	1.74	1.76
683′–686′	3′	Halite, brown, and a little green shale inclusions and polyhalite blebs. (Wine-colored stains, carnallite?).	98.0	1.22	1.25
686′–691′	5′	Halite. White and red sylvite; minor amount of brown and green shale. Blue halite.	88.0	8.80	10.00
691′–696′	5′	Halite. White and red sylvite. Blue halite. Showing of gray shale.	91.3	30.75	33.70
696′–697′	1′	Halite with a sharp reduction in amount of sylvite. Carnallite and gray-green shale.	91.0	6.23	6.86
		Interval of 14′.			
711′–713′4″	2′4″	Carnallite at 711′½″ to 711′3″, followed by halite to 712′6″, where a second seam of carnallite	------	------	------

Depth	Length of Section	Description of core	Per cent of soluble salts	Per cent of K_2O in sample	Per cent of K_2O in soluble salts
		(2″) overlies 3″ of pale-green shale. Remainder a blackish-red anhydrite.			
		Interval of 24′11″.			
738′3″–739′	9″	Polyhalite with a little anhydrite, halite, and a thin gray shale base.	-------	-------	-------
		Interval of 9′.			
748′–748′10″	10″	Dark-gray to honey-yellow anhydrite with 1″ of rose-red polyhalite at top.	-------	-------	-------
		Interval of 18′5″.			
767′3″–769′6″	2′3″	Irregular wavy mixture of red polyhalite, gray anhydrite, halite, and dark-gray clay.	66.7	7.60	11.38
		Interval of 10′4″.			
779′10″–780′6″	8″	Dark-red polyhalite.	-------	-------	-------
		Interval of 44′9″.			
825′3″–827′	1′9″	Red polyhalite at 825′3″ to 825′6″ and 826′7″ to 826′10″. Halite with polyhalite blebs and stringers between the layers. Remainder black shale and gray halite.	92.1	5.48	5.95
		Interval of 21′.			
848′–849′4″	1′4″	Red polyhalite, including grayish anhydrite, about 849′. Magnesitic black shale base with minute red halite veins.	71.8	9.24	12.85
		Interval of 1′9″.			
851′1″–851′7″	6″	Pale salmon-red waxy-textured polyhalite, becoming "smoky" and including halite in last 2″.	-------	-------	-------
		Interval of 26′8″.			
878′3″–882′10″	4′7″	Gray anhydrite, massive and shaly, with a halite layer at 878′10″ to 879′ 7″. Last 6″ gray shale with angular inclusions of halite.	-------	-------	-------

TEXAS WELLS THAT HAVE YIELDED CUTTINGS CONTAINING 5 PER CENT OR MORE OF K_2O

[Analyses by U. S. Geological Survey]

Samples marked * were not analyzed; because of limited time or small quantity of material, the K_2O content was estimated.

Well and Location	Best sample: Depth (feet)	Best sample: K_2O in sample (per cent)	Remarks (per cent of K_2O)
Andrews County			
A. G. Carter & Zweifel Co.—Cowden No. 1, center of sec. 18, block A-52, public-school land.	2425–2445	10.00	3 samples, 5.00 to 8.55.
Deep Rock Oil Co.—King No. 1, sec. 11, block A-46, public-school land.	2150–2160	7.33	4 samples, 5.03 to 6.75.
Deep Rock Oil Co.—Kuykendall No. 1, SW.¼ sec. 24, block A-46, public-school land.	2220–2230	9.75	4 samples, 5.02 to 8.39.
Deep Rock Oil Co.—Miles No. 1, sec. 22, block A-46, public-school land.	2140–2150	8.10	2 samples, 6.85 and 7.90.
Borden County			
Condor Petroleum Co., Hall No. 1, sec. 5, block 32, T. 3 N., T. & P. R.R. Co. survey.	1532-1540	5.34	3 samples, 4.00 to 5.16.
Guarantee Oil Syndicate—F. M. Long No. 1 (G. A. Jones well), NW.¼ sec. 130, block 25, Houston & Texas Central Ry. Co. survey.	1070–1075	[a]22.9	Selected sample, early polyhalite discovery.
Reeves-Parkhurst et al.—J. A. Long No. 1, SW.¼ sec. 27, block 30, T. 4 N., T. & P. R.R. Co. survey.	1695–1705	6.55	
Crane County			
Cordona Oil & Potash Co.—Cowden No. 1, SE.¼ sec. 14, block 2, H. & T. C. Ry. Co. survey.	936–940	9.60	1 sample, 5.40.
W. E. Duffey & Galt Brown Co.—Cowden No. 1, sec. 22, block X, Corpus Christi, San Diego & Rio Grande Narrow Gauge R.R. Co. survey.	895–900	13.73	8 samples, 6.24 to 9.07.
Gilliam & Connors—W. H. Penix No. 1, sec. 42, block 42, T. 4 S., T. & P. R.R. Co. survey.	2325–2340	6.17	3 samples, 5.22 to 6.03.

[a] In the soluble salts.

Well and Location	Best sample: Depth (feet)	Best sample: K_2O in sample (per cent)	Remarks (per cent of K_2O)
Gulf Production Co.—J. T. McElroy No. 1, SE.¼ sec. 203, block F, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1690–1710	10.12	11 samples, 5.02 to 8.43.
Gulf Production Co.—A. S. Crier-McElroy No. 9, sec. 186, block F, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1295–1315	12.3	1 sample, 6.2.
Gulf Production Co.—McElroy No. 3-B, NE.¼ sec. 216, block F, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1375–1400	8.50	6 samples, 6.08 to 7.54.
Penn-Tex Oil & Potash Co.—W. H. Cowden No. 1, sec. 14, block X, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1269–1273	11.32	8 samples, 5.25 to 7.85.
Gulf Production Co.—W. N. Waddell No. 2, NE.¼ sec. 10, block B-25, public-school land.	2010–2030	11.26	9 samples, 5.08 to 11.06.
Gulf Production Co.—W. N. Waddell No. 4, sec. 3, block B-25, public-school land.	2030–2050	14.60	4 samples, 7.25 to 13.87.
Henry Zweifel—W. H. Cowden No. 1, SE.¼ SE.¼ sec. 16, block X, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1565–1570	13.68	7 samples, 6.33 to 12.94.
Crockett County			
California Co.—University No. 2, sec. 34, block 7, University land.	1120–1140	5.35	1 sample, 5.26.
Cranfill Bros. Oil Co.—Harris Bros. No. 1, center of NE. ¼ sec. 4, block 3, Washington County Ry. Co. survey.	1180	6.08	2 samples, 5.80 and 5.99.
Geo. A. Henshaw & Co.—University No. 1, SW.¼ sec. 5, block 14, University land.	535–540	10.65	5 samples, 5.30 to 9.55.
Mid-Kansas Oil & Gas. Co.—Harris Bros. No. 1, SE.¼ sec. 20, block H-H, Gulf, Colorado & Santa Fe Ry. Co. survey.	1260–1310	8.92	1 sample, 8.35.
Roxana Pet. Co.—L. P. Powell No. 1, sec. 63, block BB, East Line & Red River Ry. Co. survey.	1175–1185	5.31	
California Co.—Shannon No. 1, sec. 42, block BB, Texas Central Ry. Co. survey.	1090–1095	6.12	2 samples, 5.40 and 5.65.

Well and Location	Best sample — Depth (feet)	Best sample — K_2O in sample (per cent)	Remarks (per cent of K_2O)
Gulf Production Co. — Thompson No. 1, SW.¼ sec. 71, block 1, International & Great Northern R.R. Co. survey.	985–1000	8.15	1 sample, 5.55.
Dawson County			
La Mesa Oil & Gas Co.—Burns No. 1, sec. 27, block 33, T. 5 N., T. & P. R.R. Co. survey.	1780	11.95	Early polyhalite discovery. Selected piece from 1900± feet, 15.20.
Ector County			
Texas Co. & J. S. Cosden—W. E. Connell No. 5, SE.¼ sec. 24, block B-16, public-school land.	1635–1645	7.93	2 samples, 6.77 and 7.92.
J. S. Cosden Oil Co.—Connell No. 1-B, center of NW.¼ sec. 16, block B-16, public-school land.	2025	11.40	3 samples, 5.30 to 9.07.
J. S. Cosden Oil Co.—Connell No. 1-A, center of NW.¼ sec. 13, block B-16, public-school land.	1550	11.78	7 samples, 5.02 to 7.91.
J. S. Cosden Oil Co.—W. E. Connell No. 3-A, SE.¼ NE.¼ sec 13, block B-16, public-school land.	1146–1170	9.56	2 samples, 5.85 and 5.95.
Llano Oil Co.—E. P. Cowden No. 1, sec. 5, block B-14, public-school land.	1940–1950	8.20	1 sample, 5.59.
Llano Oil Co.—T. S. Hogan No. 1, NW.¼ sec. 18, block 44, T. 3 S., T. & P. R.R. Co. survey.	1950–1965	9.08	3 samples, 5.03 to 6.57.
Southern Crude Oil Purchasing Co.—J. M. Cowden No. 1, SW.¼ NW.¼ sec. 26, block 43, T. 1 N., T. & P. R.R. Co. survey.	2395–2415	5.88	1 sample, 5.60.
Exploration Co.—Kloh, Morgan & Rumsey No. 1, NE.¼ sec. 39, block 45, T. 1 S., T. & P. R.R. Co. survey.	1580–1600	7.20	1 sample, 5.84.
Richardson & Taliaferro—Henderson No. 1, center of SE.¼ sec. 44, block 43, T. 3 S., T. & P. R.R. Co. survey.	2670	12.10	
Gulf Production Co.—State No. 3, SE.¼ sec. 1, block 35, University land.	1390–1405	10.12	3 samples, 5.20 to 7.73.
Simms Petroleum Co.—University No. 2, sec. 3, block 35, University land.	1450–1465	7.53	3 samples, 6.00 to 7.05.

Well and Location	Best sample: Depth *(feet)*	Best sample: K_2O in sample *(per cent)*	Remarks *(per cent of K_2O)*
H. F. Wurtz et al.—E. A. Ibbetson No. 1. NW.¼ sec. 16, block 46, T. 3 S., Gunter, Munson, Maddox Bros. & Anderson.	1525–1545	*5.00	1 other sample, 5.00 (est.).
Gaines County			
Landreth Production Co.—Alley No. 1, NW.¼ sec. 2, block A-30, public-school land.	2160–2170	9.28	8 samples, 5.20 to 8.90.
Cranfill & Reynolds and Louisiana Production Co.—Ralph No. 1, SW.¼ sec. 7, block 28, public-school land.	2560–2561	8.50	3 samples, 5.87 to 7.73.
Glasscock County			
Landreth Production Co.—Houston No. 1, NE.¼ NW.¼ sec. 12, block 35, T. 2 S., T. & P. R.R. Co. survey.	1550–1555	8.30	4 samples, 5.50 to 7.38.
General Oil Co.—McDowell No. 4, sec. 34, block 34, T. 2 S., T. & P. R.R. Co. survey.	1035–1050	10.03	Early polyhalite discovery.
Irion County			
Kirby Petroleum Co.—Sawyer Cattle Co., Bar S No. 1, sec. 3047, block 25.	902–908	6.03	
Loving County			
California Co.—Allen No. 1, sec. 90, block 1, Waco & Northwestern R.R. Co. survey.	1615–1635	7.04	3 samples, 5.50 to 6.94.
California Co.—Allen No. 2, sec. 90, block 1, W. & N.W. R.R. Co. survey.	1015–1030	5.50	2 samples, 5.01 and 5.12.
Lockhart & Co.—R. L. Allen No. 1, sec. 82, block 33, H. & T. C. Ry. Co. survey.	810–815	9.80	3 samples, 5.00 to 8.17.
Eldridge core test, sec. 22, block C-26, public-school land.	1121	10.48	Sample selected from 1123, 1125, and 1126 feet, 15.08.
Owen & Sloan—Johnson No. 1, sec. 20, block 53, T. 2, T. & P. R.R. Co. survey.	1100–1110	11.47	6 samples, 6.53 to 7.63.
Kingwood Oil Co.—T. O. Moore No. 1, center of NE.¼ sec. 2, block C-25, public-school land.	1440–1450	5.03	
Pinal Dome Corporation—Means No. 1, sec. 23, block C-26, public-school land.	990–995	11.21	8 samples, 5.03 to 9.00.

Well and Location	Best sample — Depth (feet)	Best sample — K_2O in sample (per cent)	Remarks (per cent of K_2O)
California Co. — Reagan-McIlvain No. 1, sec. 84, block 1, W. & N.W. R.R. Co. survey.	890–900	9.63	4 samples, 5.34 to 7.92.
California Co. — Reagan-McIlvain No. 4, sec. 84, block 1, W. & N.W. R.R. Co. survey.	965–980	9.85	6 samples, 5.41 to 9.75.
California Co. — Reagan-McIlvain No. 5, sec. 84, block 1, W. & N.W. R.R. Co. survey.	900–915	5.30	
Martin County			
Humble Oil & Refining Co.—C. C. Slaughter No. 1, NE.¼ sec. 8, block 35, T. 3 N., T. & P. R.R. Co. survey.	1920–1925	6.17	1 sample, 5.83.
Midland County			
West Texas Oil Corporation and States Oil Corporation — Bryant No. 1, NE.¼ sec. 9, block 39, T. 3 S., T. & P. R.R. Co. survey.	2405–2411	8.94	Early polyhalite discovery.
Rook-Zimmerman et al. — Hill Bros. No. 1, sec. 8, block 37, T. 5 S., T. & P. R.R. Co. survey.	2220–2230	9.50	3 samples, 6.37 to 7.90.
Pecos County			
Buell & Hagan—Jasper No. 1, near center sec. 1, block 104, Jasper County school land.	1775–1785	6.49	
G. A. Henshaw—B. T. Corder No. 1, center of SW.¼ sec. 74, block 2, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1530–1540	5.00	Sample weighed less than 1 gram.
Kirby Petroleum Co.—Harrall No. 1, sec. 35, block C-4, G.,C. & S.F. Ry. Co. survey.	1500–1515	7.52	2 samples, 5.00 and 5.21.
Olean Petroleum Co.—G. N. Harrall No. 1, center of SW.¼ sec. 82, block R-3, G., C. & S.F. Ry. Co. survey.	1320–1330	10.30	4 samples, 5.14 to 10.17.
Kershaw & Livingston — Cannon No. 1, NW.¼ NE.¼ sec. 54, block A-2, T. C. R.R. Co. survey.	1456–1463	11.30	
George Anderson et al.—McKenzie No. 1, center of SE.¼ N.½ sec. 6, block 604, G.,C. & S.F. Ry. Co. survey.	1100–1110	*5.00–10.00	Estimated; sample weighed less than 1 gram; 1 other sample, 5.00 (est).

Well and Location	Best sample Depth (feet)	Best sample K_2O in sample (per cent)	Remarks (per cent of K_2O)
Moody Oil Corporation—B. T. Corder No. 1, center of SW.¼ sec. 77, block 2, C.C., S.D. & R.G. N.G. R.R. Co. survey.	1300–1350	6.74	1 sample, 5.40.
Michaelson & Talbot — Riverbed No. 1, 45 feet north and 45° west from northwest corner of sec. 10, block 9, Houston & Great Northern R.R. Co. survey.	855–862	*5.60	4 samples 5.00+ (est.), weight less than 1 gram.
Allsman-Bell—Riverbed No. 2, 564 feet east and 665 feet south from northeast corner sec. 64, block 1, I. & G. N. R.R. Co. survey.	675–690	9.46	
G. H. Anderson & C. E. Menzie—Sherbino No. 1, sec. 43, block C-4, G., C. & S.F. Ry. Co. survey.	980–990	5.79	1 sample, 5.00.
Reagan County			
California Co.—University No. 1, NW.¼ NE.¼ sec. 13, block 8, University land.	1505–1510	8.25	2 samples, 5.35 and 6.80.
Gulf Production Co. — Campbell-State No. 1, NW.¼ sec. 1, block 1, University land.	1515	13.60	
Gulf Production Co.—Sowell-State No. 1, SW.¼ sec. 28, block 58, University land.	1210–1230	9.16	
W. H. Dunning & Humble Oil & Refining Co.—Sawyer Cattle Co. No. 1, SE.¼ SW.¼ sec. 93, block 1, T. & P. R.R. Co. survey.	1190	5.30	
Texon Oil & Land Co.—Texon No. 1, NW.¼ NW.¼ sec. 1, block 8, University land.	1405–1415	9.56	2 samples, 6.41 and 7.80.
Texon Oil & Land Co.—Texon No. 3, group 1, NW.¼ sec. 36, block 9, University land.	-1255	11.25	2 samples, 7.50 and 10.22.
Texon Oil & Land Co. — Santa Rita No. 1, sec. 2, block 2, University land.	1316–1325	8.29	4 samples, 5.63 to 7.88.
Texon Oil & Land Co.—Santa Rita No. 2, sec. 2, block 2, University land.	1405–1415	9.27	
Texon Oil & Land Co.—Santa Rita No. 3, sec. 2, block 2, University land.	1305–1325	9.75	1 sample, 7.90.

Well and Location	Best sample Depth (*feet*)	Best sample K_2O in sample (*per cent*)	Remarks (*per cent of K_2O*)
Big Lake Oil Co.—Santa Rita No. 4, NE.¼ NW.¼ sec. 35, block 1, University land.	1265–1280	5.42	
Big Lake Oil Co.—Santa Rita No. 7, NE.¼ NE.¼ sec. 27, block 1, University land.	1725–1735	8.05	4 samples, 6.09 to 7.95.
Big Lake Oil Co.—Santa Rita No. 8, SE.¼ sec. 2, block 2, University land.	1280–1290	5.98	3 samples, 5.48 to 5.98.
Big Lake Oil Co.—Santa Rita No. 9, SE.¼ NE.¼ sec. 2, block 2, University land.	1276–1295	5.85	3 samples, 5.12 to 5.70.
Big Lake Oil Co.—Santa Rita No. 11, SW.¼ SW.¼ sec. 24, block 9, University land.	1470–1490	8.82	
Texas Co.—J. D. Sugg No. 1, sec. 107, block 2, T. & P. R.R. Co. survey.	1110–1120	7.81	
Texas Co.—J. D. Sugg No. 3, center of sec. 165, block 2, T. & P. R.R. Co. survey.	1146–1160	5.27	
Upton County			
Sun Oil Co.(?)—A. S. Burleson No. 1, sec. 100, T. C. Jones survey.	1280–1295	6.51	
Sun Oil Co.—A. S. Burleson No. 5, sec. 100, T. C. Jones survey.	1200	7.77	3 samples, 5.02 to 7.05.
Dixie Oil Co.—E. S. Hughes No. 1, NW.¼ sec. 4, William M. Teer survey.	838–845	11.90	8 samples, 5.98 to 9.94.
Germany et al.—H. M. Halff No. 1, sec. 50, Phillips survey.	1790–1800	5.45	1 sample, 5.26.
W. W. Donnelly & L. E. Hultz—H. M. Halff No. 1, sec. 76, block Y, T.C. R.R. Co. survey.	1985–2000	6.40	2 samples, 5.31 and 5.55.
Crosby Drilling Co.—Lane No. 1, sec. 36, block 1, Missouri, Kansas & Texas R.R. Co. survey.	1115–1135	7.03	2 samples, 5.75 and 6.37.
Southern Crude Oil Purchasing Co.—C. W. Hobbs No. 1, sec. 61, block 35, H. & T. C. Ry. Co. survey.	740–754	9.85	1 sample, 6.17.
Republic Production Co.—M. L. Baker No. 1, sec. 8, block 35, H. & T. C. Ry. Co. survey.	1060–1155	12.72	

Well and Location	Best sample Depth *(feet)*	Best sample K_2O in sample *(per cent)*	Remarks *(per cent of K_2O)*
Plateau Oil & Gas Co. — Union Land Co. No. 1, sec. 34, block 1, M., K. & T. R.R. Co. survey.	1115–1120	7.24	
Kirkwood et al. — Rankin No. 1, sec. 27, Houston, East & West Texas R.R. Co. survey.	1565–1580	5.06	
Regan-Bell—Flat Rock No. 1, NE. ¼ sec. 2, block 4, University land.	1540–1552	10.18	1 sample, 5.40.
Roxana Petroleum Corporation—Della Bowen No. 1, NW.¼ sec. 6, G.,C. & S.F. Ry. Co. survey.	890–920	12.40	4 samples, 5.74 to 10.80.
Roxana Petroleum Corporation—Della Bowen No. 2, NW.¼ sec. 6, G., C. & S. F. Ry. Co. survey.	910–925	8.20	
Roxana Petroleum Corporation—E. S. Hughes No. 1, sec. 4, William M. Teer survey.	1010–1020	5.35	
Gulf Production Co.—Sanger No. 1, 330 feet south of center of north line, sec. 14, block 3, M., K. & T. R.R. Co. survey.	1770	11.20	
Atlantic Oil Co. — Sherk No. 1, sec. 35, block 1, M., K. & T. R.R. Co. survey.	1130	6.57	6 samples, 5.12 to 6.28.
Skelly Oil Co.—Jones No. 1, sec. 32, block 41, T. 4 S., T. & P. R.R. Co. survey.	2390	8.00	4 samples, 5.45 to 7.66.
Texas Co. & Cordova Union—Union Land Co. No. 1, sec. 23, block 35, H. & T. C. Ry. Co. survey.	762–775	6.72	1 sample, 6.37.
Texas Co.—Union Land Co. No. 1, sec. 53, block 35, H. & T. C. Ry. Co. survey.	1020–1040	6.03	
Virginia - Texas Co. — University No. 1, SE.¼ sec. 14, block 15, University land.	1355–1405	10.42	4 samples, 5.65 to 8.70.
Ward County			
Arthur Pitts Oil Co.—River Well No. 1, sec. 25, block 33, H. & T. C. Ry. Co. survey.	1600–1610	9.03	3 samples, 5.60 to 6.29.
Chesapeake Oil Co.—Marston No. 1, sec. 10, block B-19, public-school land.	1095	13.83	Selected material; 1 sample, 9.10.

Well and Location	Best sample: Depth (feet)	Best sample: K_2O in sample (per cent)	Remarks (per cent of K_2O)
Texas Oil Production Co.—Redmond No. 1, sec. 162, block 35, H. & T. C. Ry. Co. survey.	1785	9.95	1 sample, 8.87.
Winkler County			
Ladd, Hill et al. (Tidal Oil Co.) J. W. Amburgey No. 1, sec. 24, block B-7, public-school land.	1745	6.29	1 sample, 5.04.
Gibson & Johnson—Leck No. 1, sec. 30, block 74, public-school land.	2020–2040	6.23	3 samples, 5.12 to 5.70.
Skelly Oil Co.—M. M. Leeman No. 1, SW.¼ sec. 21, block 75, public-school land.	2235–2241	12.60	5 samples, 5.06 to 12.13.

THE POTASSIUM SULFATE MINERAL POLYHALITE IN TEXAS

W. A. CUNNINGHAM[1]

The investigations on which this paper is based were undertaken by direction of the Regents of The University of Texas and were made under direction of Dr. H. P. Bybee, Geologist of the University Lands Survey. The object of the investigations was to accumulate information on potassium minerals, particularly the sulfate mineral polyhalite, in the southern Permian basin in Texas in which lands owned by The University of Texas are located. The author desires to thank the members of the geologic staff of the University Lands Survey for assistance and suggestions, many of which have been incorporated in this paper.

Although some potash in its various forms is used in the manufacture of glass, soap, chemicals, and for other purposes, 90 or 95 per cent of the total amount produced is used as plant food in fertilizers. Hence, in this report concerning the mineral polyhalite, its use as an agricultural fertilizer only will be considered. The following table shows the approximate consumption of potash in fertilizers from 1923 to 1928.

Consumption of Potash for Fertilizer Use in the United States, 1923 to 1928, in Short Tons of K_2O[2]

Year	Kainite	Manure Salt	Muriate	Sulfate	Total From Imports	From Domestic Sources	Total Consumption for Fertilizer Use
1923	23,291	60,344	78,879	34,696	194,210	19,281	213,491
1924	21,764	51,800	72,312	41,203	187,079	21,880	208,959
1925	25,391	86,068	90,176	37,532	239,167	25,802	264,969
1926	25,259	70,883	111,525	38,033	245,700	25,060	270,760
1927	16,150	74,725	95,505	38,590	224,970	49,500	274,470
1928	16,780	108,775	136,065	48,420	310,040	60,370	370,410
Average per year	21,440	75,433	96,910	37,748	233,528	33,649	267,166

Since 1928 there has been a very radical decrease in the total amount of potash used for fertilizer purposes. There has been a tendency to increase the percentage of muriate at the expense of the lower grade kainite and manure salts; the relative amount of potassium sulfate has remained essentially constant at approximately 15 per cent of the total.

[1]Chemical Engineer, Department of Chemistry, The University of Texas.

[2]U. S. Bur. Mines, Mineral Resources of the United States, Part II, Non-metals; chapters on potash for the years indicated.

The average sales prices of bulk potash salts, c.i.f. American Atlantic Ports, is given below. The quotations for the years 1923–1929 are based on 80 per cent potassium muriate, 90 per cent potassium sulfate, and 48 per cent sulfate of potash magnesia. For 1932 these percentages are, respectively, 85, 95, and 50 per cent.

Type of Salt	Basis of Price Quotation Per Cent K_2O	1923	1924	1925	1926	1927	1928	1929	1932
Kainite	12.4	$ 6.50	$ 6.59	$ 7.10	$ 7.72	$ 8.46	$ 8.28	$ 8.55	$
Manure salt	20.0	9.50	8.97	10.15	10.86	11.66	11.37	11.75	
Muriate	50.5	32.00	29.37	30.10	30.68	32.71	31.99	33.04	35.55
Sulfate	48.7	39.20	38.97	40.14	41.00	42.96	42.00	43.38	46.10
Sulfate of potash magnesia	25.4	23.15	22.40	22.59	23.06	24.11	23.57	24.35	26.20

It should be noted that during this period of time, 1923–1932, sulfate sales averaged 17 per cent of the imports and nearly 15 per cent of the total consumption, and this in spite of the fact that the average difference in cost of sulfate and muriate was $9.70 per ton. This is definite assurance that there is a demand for sulfate which is sufficiently strong to uphold a substantial premium. At the present time, no appreciable amount of sulfate salts of potash are being produced commercially in the United States. Hence, any new source of potassium sulfate would have to meet the prices of imported potash only.

The average amount of potash as sulfate used in the United States during 1923–28 was 37,748 tons. This is roughly equivalent to 70,000 tons potassium sulfate and to 242,000 tons of polyhalite. If all this sulfate were supplied in the form of polyhalite, it would mean a daily production of some 700 tons.

Bureau of Mines Bulletin No. 316, "Commercial Possibilities of the Texas-New Mexico Potash Deposits," pages 23–26, 1930, gives the following information concerning the use of sulfate of potash:

> Sulfate of potash is widely used in the growing of citrus fruits. The deleterious effect of excessive chlorine in lowering the free-burning quality of tobacco is well recognized. Tobacco thrives best when supplied with fertilizer in which the chlorine content is kept below 2 per cent. Under favorable conditions small amounts of chlorine stimulate plant growth, increase the yield, and give the plants increased resistance against drought by increasing the amount of water stored in the leaves. Although small amounts of chlorine

are beneficial, excessive chlorine causes serious injury to the tobacco plants, and a coöperative committee representing both the Federal Bureau of Plant Industry and State authorities in the southern tobacco-growing states made the following comment in recommending fertilizers for tobacco culture:

"Available experimental data at this time from bright tobacco sections of Virginia, North Carolina, South Carolina and Georgia, show that a small quantity of chlorine in the tobacco fertilizer increases the acre value of the crop. Experience has shown, however, that an excessive amount of chlorine in fertilizers used for tobacco injures its growth, producing a thick, brittle leaf, and also has an unfavorable effect upon its burning quality. It is recommended, therefore, that fertilizers be compounded in such proportions that the fertilizer mixtures shall contain a maximum of 2 per cent of chlorine."

The recommendation was dated October 17, 1928, but was not followed entirely by the fertilizer manufacturers, and fertilizers offered for sale in the tobacco-growing states and used in growing the 1929 crop contained high percentages of chlorine.

The poor quality of the 1929 crop wherever the committee's recommendations were ignored has given striking proof of the injury caused by excessive chlorine and has been fully recognized and laid to its proper causes by both Federal and State agricultural authorities. As a result of this year's experience it seems likely that the use of fertilizers containing sulfate salts of potash and having a low chlorine content will be increased greatly in the tobacco-growing states.

Polyhalite and its sulfate products, therefore, are not only suitable ingredients for fertilizers but fulfill certain special requirements for which there is now an active demand. The use of domestic polyhalite and its sulfate products will, however, depend upon the price at which they can be delivered to a consumer as compared with the price of potash from other sources.

That the greater part of the sulfate is being used in the tobacco and citrus growing localities is shown in the table on page 836.

From this it is seen that approximately three-fourths of all the potassium sulfate enters the country at the Atlantic seaboard ports. Although no data are available concerning the ultimate users of this material, it is probably used in the territory within a few hundred miles of its port of entry.

Polyhalite is a complex sulfate of potash, magnesia, and lime; when pure it contains 15.6 per cent of K_2O. Its chemical formula is $2CaSO_4.MgSO_4.K_2SO_4.2H_2O$.

The following quotation is taken from Bureau of Mines Bulletin No. 316, pages 21–23:

Physically, polyhalite is a dense, fine-grained, practically opaque mineral with a specific gravity of 2.8 and a hardness of 2.5 to 3. Its physical properties are similar to those of a fine-grained, compact, pure limestone, although it is

Short Tons of Potash as Sulfate Imported Into the United States for Use in Fertilizers[3]

Point of Entry	K_2O as Sulfate 1927	1928
Massachusetts	500	1,880
New York	3,150	1,385
Philadelphia	465	510
Maryland	1,560	3,420
Virginia	1,750	2,895
North Carolina	1,125	2,265
South Carolina	520	1,210
Georgia	2,840	3,405
Florida	15,990	18,630
Mobile	440	620
New Orleans	545	625
Galveston	70	120
California	2,780	5,825
Washington and Oregon	80	135
Hawaii	4,480	3,595
Porto Rico	2,225	1,900
All others	70	--
TOTAL	38,590	48,420
Per cent of total imports	17.2	15.6

much more brittle. In color, polyhalite is usually deep brick red, but this varies through flesh-pink to salmon-pink and yellow. It also occurs as a pure white mineral.

Polyhalite in contact with water breaks down into its constituents; the sulfates of potash and magnesia go readily into solution, leaving a surface coating of gypsum ($CaSO_4$) on the polyhalite particles that partly protects them from further attacks by the solvent and retards the rate of solution. In a large excess of water this gypsum will also be slowly dissolved. The fineness of the material and the relative amount of water used are factors in the rate of solution. Experiments at the New Brunswick (N. J.) station of the Bureau of Mines with polyhalite from test well 2 in New Mexico show that, using 4 parts of water to 1 part of polyhalite at ordinary room temperatures (21° C.), the potash minerals will all pass into solution in 2 to 10 days, depending upon the degree of fineness of the material.

The amount of potash in a fertilizer that is considered "available" plant food is the amount soluble in distilled water. Various state laws regulating the manufacture and sale of fertilizers establish standards for "available" potash content, measured by water solubility, and impose penalties and fines for failure to meet these standards. Strictly speaking, polyhalite is soluble in distilled water, but owing to the fact that it takes on a protective coating of gypsum in the presence of moisture its rate of solubility is rather slow and there is a prejudice among manufacturers and users of fertilizer against potash salts that are not quickly and completely soluble in small amounts of water. This prejudice is emphasized by the possibility of very strict interpretation of the state laws with regard to solubility of potash content.

[3]Wroth, J. S., Commercial possibilities of the Texas-New Mexico potash deposits: U. S. Bur. Mines, Bull. 316, pp. 29-30, 1930.

This prejudice against polyhalite is thought to be unjustified by the fact that in spite of its slow solubility the potash content of polyhalite is actually "available" as plant food when the polyhalite is spread directly on the soil and exposed to soil conditions. Pot tests with alfalfa at the New Mexico College of Agriculture and Mechanic Arts have indicated that finely ground polyhalite is quite as efficient as commercial potassium sulphate. Further tests on a larger scale are in progress at various agricultural stations throughout the country working in coöperation with the Bureau of Mines. Should these tests confirm the opinion that all the potash in crude polyhalite is available plant food, crude polyhalite would appear to have natural advantages over the more soluble potash salts under certain conditions. Its slow decomposition would cause it to be retained in wet soils that require draining, and the potash applied to the soil in this form would not be removed rapidly by excessive rainfall during heavy storms, as was the case in many of the southern states after the Florida hurricane in 1926.

Pure polyhalite contains 15.6 per cent of potash and when produced commercially should contain 12 to 14 per cent. Crude polyhalite can not, therefore, be used conveniently as an ingredient of fertilizers containing more than 16 to 20 units of plant food. For mixtures having the ratios 4 8–4 and 4–12–4 and for all lower-grade mixtures, crude polyhalite would appear to be a satisfactory form of potash, if it can be supplied on a price parity, as regards potash content, with the low-grade foreign salts now used. Crude polyhalite would have an advantage over these low-grade foreign salts in that it is entirely a sulphate, while the foreign kainites and manure salts contain potash in the chloride form.

A factor in the possible market for crude polyhalite is the well-recognized trend toward the use of higher-grade and more concentrated fertilizers, a striking feature of the fertilizer trade at the present time.

In spite of this trend a certain amount of low-grade fertilizer will always be used and for its manufacture there is a more or less constant annual demand for 100,000 to 150,000 tons of low-grade potash salts.

During the past few years much work has been done to determine whether or not polyhalite *per se* may be used as a fertilizer. Without exception these experiments have shown that the potash in polyhalite is available for plant use and that it can be used instead of sulfate of potash in practically all cases. The exception is in that class of fertilizers in which the potash content is so high that it can be obtained in the mix only through the use of a potash salt having a K_2O content greater than that of polyhalite. Such fertilizers, however, make up a very minor portion of the total potash fertilizers used.

It has been shown conclusively by various agricultural experiments that both lime and magnesia, particularly magnesia, are very important and essential to plant growth. This demand for magnesia is particularly noticeable in the growth of tobacco, corn, and cotton.

The following quotations are taken from publications relating to the use of polyhalite:

Crude polyhalite and mixed salts containing crude polyhalite contain the sulfates of potash, magnesia and lime, and would appear to be eminently suitable where magnesia and lime are required and where the chlorine content must remain low. . . . In mixtures of crude polyhalite and refined potassium sulfate to yield the 20 and 30 per cent commercial grades the presence of the sulfates of magnesia and lime would be of an advantage and an active market would be assured provided these salts can be sold on a par with the corresponding grades of chloride salts. . . . Polyhalite and its sulfate products, therefore, are not only suitable ingredients for fertilizer, but fulfill certain special requirements for which there is an active demand.[4]

Fraps has recently written as follows: The potash of polyhalite is not completely soluble in water, but 73.2 per cent of the total potash in polyhalite ground to pass a 20-mesh sieve was found to be soluble in water by the A.O.A.C. method of potash in fertilizers. The availability of potash in finely ground polyhalite (—20 mesh), as found on the average of eight pot experiments, was 96 per cent of that of sulfate or muriate of potash. The potash in polyhalite which passed a 10-mesh sieve but did not pass a 20-mesh sieve was 36.8 per cent soluble in water. The availability of potash in four pot experiments was equal to that of muriate of potash. Polyhalite is suitable for use as a potash fertilizer when ground to pass a 20-mesh sieve.[5]

On the basis of these tests, polyhalite seems to be in no way inferior to the customary K_2SO_4 as a fertilizing agent. Although the fine material (—40 mesh) gave less increase in crop than was obtained using K_2SO_4, the polyhalite crushed to 20 to 40-mesh gave slightly better results, so that the average of the two is very similar to the crop increase from K_2SO_4.

Yields of Alfalfa in Pot Tests (New Mexico College of Agriculture and Mechanic Arts). Treatment Per Acre: 200 Pounds $(NH_4)_2SO_4$, 800 Pounds 18 Per Cent Acid Phosphate, 400 Pounds Potash Salts

	Yields, Air Dry, Grams				
Potash salt	First Crop	Second Crop	Third Crop	Total	Increase Over No Potash Per Cent
None	7.5	8.5	11.5	27.5	--
Commercial K_2SO_4	10.8	9.9	12.4	33.1	20
Polyhalite through 40-mesh	9.8	10.0	11.4	31.2	13
Polyhalite 20 to 40-mesh	9.0	11.1	13.2	33.3	21

[4] Wroth, J. S., *op. cit.*, p. 25.

[5] Fraps, G. S. Availability to plants of potash in polyhalite: Texas Agri. Exp. Station, Bull. 449, p. 15, 1932

That the two treatments were equally effective is more significant when one considers that the actual K_2O content of the polyhalite applied was less than one-third that of the K_2SO_4. Four hundred pounds of commercial K_2SO_4 contains about 200 pounds of K_2O, while 400 pounds of polyhalite would contain not more than 60 pounds of K_2O.[6]

At the present time the Texas Agricultural Experiment Station is conducting a series of relatively large-scale experiments on the use of polyhalite. Through the courtesy of the United States Potash Company some two and one-half tons of mixed red and "white" polyhalite were obtained from the company's second shaft and shipped direct to College Station. The material was somewhat contaminated with salt and anhydrite but was the best obtainable in quantities sufficient for field experimentation. These tests are not yet completed, but Dr. E. B. Reynolds, Chief of the Division of Agronomy, has written the following in a private communication:

As you will recall we compared red polyhalite, white polyhalite, and muriate of potash where these materials supplied the same amount of K_2O in a complete fertilizer, which was applied to both cotton and sudan grass. The results obtained on cotton indicate that both the red and white polyhalite were equal or superior to muriate of potash. As a matter of fact, the fertilizer which contained red polyhalite increased the yield of cotton 23 per cent over the unfertilized soil. The fertilizer containing the white polyhalite increased the yield 18 per cent and the muriate 10 per cent over the yield of cotton on the untreated soil.

On the other hand, muriate was slightly but probably not significantly better than polyhalite for sudan grass. The fertilizer in which the muriate supplied the potash made a gain of 24 per cent over the yield of the sudan grass on the untreated soil. The treatments in which red polyhalite and white polyhalite supplied the potash increased the yield of sudan grass 20 and 19 per cent, respectively, over the soil which received no fertilizer.

These meager results with cotton and sudan grass indicate that the potash in polyhalite is just as available as the potash in muriate of potash, which is the most important form of potash used in American fertilizers.

Dr. Reynolds' results are particularly interesting since his work is the first which has been conducted on a scale large enough to give definite information concerning the possible commercial value of polyhalite. He is continuing his work and doubtless will publish the results of his experiments when they are finished.

[6]Partridge, C. P., and Emery, A. H., Manufacture of potassium salts from polyhalite and their significance as fertilizer materials: *The American Fertilizer*, p. 10. Oct. 7, 1933. The four results quoted are those obtained by Jordon and McKittrick of the New Mexico College of Agriculture and Mechanic Arts.

Much more work has been done on the development of suitable refining processes for polyhalite than for adapting it for use *per se.* Schoch,[7] Fraas,[8] Partridge,[9] Storch,[10] and others have been most aggressive in this phase of the work. Of all refining methods so far proposed, the one by Schoch appears to be greatly superior from the standpoint of economical operation. In this process the finely ground polyhalite is mixed with lime slurry and heated for about fifteen minutes at 220° C. At the end of this period of "cooking," a solution containing some 12 to 13 per cent potassium sulfate is obtained. The remaining solid is readily freed of all residual potassium sulfate and contains the magnesium in such a form that it can be removed easily and converted to light carbonate of magnesium. After removal of the magnesium, the anhydrite is easily hydrated and is then converted into a gypsum plaster of unusually high tensile strength.

It is entirely possible, and indeed probable, that the next few years will see the development of a domestic source of potassium sulfate of any desired grade, through a combination of crude polyhalite and refined potassium sulfate in any desired ratio. Such an industry would not be a competitor of the recently developed mines in New Mexico but would be a complement to them in that both potassium chloride and sulphate would be supplied from domestic sources.

HISTORY OF DEVELOPMENT

The existence of some form of potash in the Permian basin of west Texas has been known since 1912 when, at the suggestion of Dr. J. A. Udden[11] of The University of Texas, water samples from a well being drilled at Spur, Dickens County, were tested and found to contain considerable quantities of soluble potash.

Following this discovery the Bureau of Economic Geology obtained samples from a number of wells in west Texas and discovered potash in three of them as follows: the Borden well in Potter

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[7]Schoch, E. P., Potassium sulfate from polyhalite: Ind. Eng. Chem., vol. 27, p. 467, 1935. For summary of this paper see page 868.

[8]Fraas, F., and Partridge, E. P., Potash and polyhalite by reduction process: Ind. Eng. Chem., vol 24, p. 1028, 1932

[9]Partridge, E. P., Texas-New Mexico polyhalite as a source of potash for fertilizer: Ind. Eng. Chem., vol. 24, p. 895, 1932.

[10]Storch, H. H., Extraction of potash from polyhalite: Ind. Eng. Chem., vol. 22, p. 934, 1930.

[11]Udden, J. A., The deep boring at Spur: Univ. Texas Bull. 363, 90 pp., 1914; reprinted, 1926.

County, the Miller well in Randall County, and the Adrian well in Oldham County. The United States Geological Survey became interested and in the winter of 1915-1916 started a test well at Cliffside, Potter County. This well was drilled to a total depth of 1703 feet without encountering any potash.

During the period of 1918 to 1921, inclusive, the Bureau of Economic Geology and the United States Geological Survey coöperated in the collection and testing of samples from wells drilled in west Texas during that time. Polyhalite was identified in cuttings from the following wells: the Bryant well in Midland County; the Pitts Oil Company River Bed well in Ward County; the Burns well in Dawson County; the Means well in Loving County; the Long or G. A. Jones well in Borden County; and the McDowell well in Glasscock County. Due to lack of funds, the Bureau of Economic Geology was forced to drop its part of the work in September, 1921, but the U. S. Geological Survey continued its investigatoins.[12]

Until 1925 all investigations were limited to more or less qualitative examinations of cuttings from wells being drilled in a search for oil. In July, 1925, the Standard Potash Company, now the Texas Potash Corporation of Texas, began the first of two core wells sunk in southwest Midland County on the Jones ranch.[13] Soon afterwards the Gypsy Oil Company and the Snowden & McSweeney interests began a series of core tests in New Mexico which ultimately resulted in the opening, early in 1932, of what is now the United States Potash Company mine in Eddy County.

In 1926 the United States Congress passed an act authorizing the U. S. Geological Survey and the Bureau of Mines to spend $100,000 per year for five years for prospecting for potash. As a result, twenty-four core wells were drilled in Texas, New Mexico, and Utah. Location of these wells is given in pages 664–667 of this volume. The five-year period of exploration expired in June, 1931, and the final summary of results was given in a Department of Interior press release dated May 9, 1932. A more complete statement of these explorations has been given on pages 653–658 of this volume.

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[12]Mr. O. C. Wheeler carried on this work during the years 1919–1920, and Mr. D. D. Christner during the years 1920–1922.

[13]Sellards, E. H., and Schoch, E. P., Core drill tests for potash in Midland County, Texas: Univ. Texas Bull 2801, pp. 159–201, 1928.

From the date of its organization in July, 1929, the geologic staff of University Lands has consistently gathered all available information concerning the nature and extent of the salt section in the southern part of the Permian basin and in 1932 the Board of Regents decided to conduct a systematic examination for potash minerals of all available cuttings from wells drilled in this region. It was realized that such examinations could be of a qualitative nature only, but there was the possibility that the logs of the wells so examined might be correlated with those of the core tests previously made and thus permit some conclusion to be drawn concerning the extent of the potash-bearing formations.

The investigations proceeded in two ways: (1) by microscopic and chemical examination of well cuttings and (2) by chemical examination of water samples taken from wells drilling through the salt sections. It is not likely that the well cuttings would retain any soluble potash minerals, and hence the water samples were taken in order to see if they might be of value as "indicators" of the presence of strata of the soluble minerals. Any polyhalite encountered in the well would probably show up in the cuttings because its relatively low solubility would prevent its being appreciably dissolved by the drilling water. It was found that this mineral was ordinarily easily recognized, especially when the sample was examined under water, although, in a few instances, red anhydrite was confused with polyhalite. Chemical examination of samples was limited to determination of the potassium content of cuttings and drilling water and to the magnesium content of the latter.

At the very beginning it was realized that the nature of the samples involved did not warrant the use of either the chloroplatinic acid or the perchloric acid methods for determination of potassium content. These methods were further condemned by the fact that it would have been almost impossible to make the large number of analyses by either method within a reasonable length of time. Consequently, a variation of the cobalti-nitrite method was adopted. This variation was developed by Dr. E. P. Schoch, Director of the Bureau of Industrial Chemistry, The University of Texas, and has been used for potash determinations in the Bureau for several years.

Details of the method are as follows:

(1) Pour a small portion of the sample into a mortar and crush to a fine powder.

(2) Weigh out an accurate 1 gram sample and put into a 250 ml. beaker containing about 50 ml. water.

(3) Add 10 ml. of a 10 per cent sodium carbonate solution and boil for 30 minutes. Add water as required to keep at least 50 ml. in the beaker. Polyhalite and other potash salts are completely decomposed by this treatment and the potassium goes into solution.

(4) Filter and wash with hot water.

(5) Make filtrate slightly acid to litmus with a few drops of glacial acetic acid and evaporate to 25–35 ml. CAUTION: Do not carry the evaporation so far that crystals will form when the liquor cools.

(6) Transfer to precipitation tube, make total volume up to 50 ml., add 15 ml. cobalti-nitrite reagent, shake well, and let set 30 minutes before reading. In case some of the precipitate sticks to the side of the tube it may be loosened by rotating the tube.

(7) A tube containing a known amount of potash should be precipitated at the same time and the volume of precipitate resulting therefrom should be used in calculating the potash in the unknown sample.

(8) The standard potash solution is an accurate 3 per cent K_2SO_4 solution; 5 ml. of this solution contain 0.15 grains K_2SO_4 or 0.082 grams K_2O.

The precipitation tube used is the standard 100 ml. oil centrifuge tube, ASTM serial designation D 96–28. Pyrex glass tubes of this design are preferred since they tend to be more uniform. It is highly important that these tubes be kept scrupulously clean; they should be washed with chromic acid immediately preceding each determination. Inasmuch as temperature, volume of solution, amount of reagent, and several other factors affect the rate and extent of the settling of the precipitate, a "standard" tube should be prepared each time a determination is made.

The volume of precipitate should never be over 0.5 ml. If the 1 gram sample yields a larger amount, the determination should be repeated with a sample of only 0.5 gram. Cobalti-nitrite reagent is prepared as follows:

Solution A

113 grams cobaltous acetate
100 ml. glacial acetic acid
water to make up to 500 ml.

Solution B

220 grams sodium nitrite
water to make up to 500 ml.

Mix equal volumes of the solutions A and B and keep under vacuum overnight to remove gases formed. The mixture should be kept in an amber bottle and not used after it is two weeks old. Small amounts of the reagent may be prepared for immediate use without subjecting it to the vacuum treatment.

Since the inception of this survey, samples from approximately three hundred wells have been examined and a descriptive log of each well has been made. Chemical analyses have been made on about one thousand samples of brine and well cuttings. All other available information has been gathered together, including descriptive logs of all United States Geological Survey core wells and many of those of private operators. All information has been carefully tabulated, in so far as it is possible to do so, and contour maps made showing the top of the salt and thickness of the salt section over the entire southern portion of the Permian basin. On Figure 35 is shown a thickness map of the upper salt of the Permian

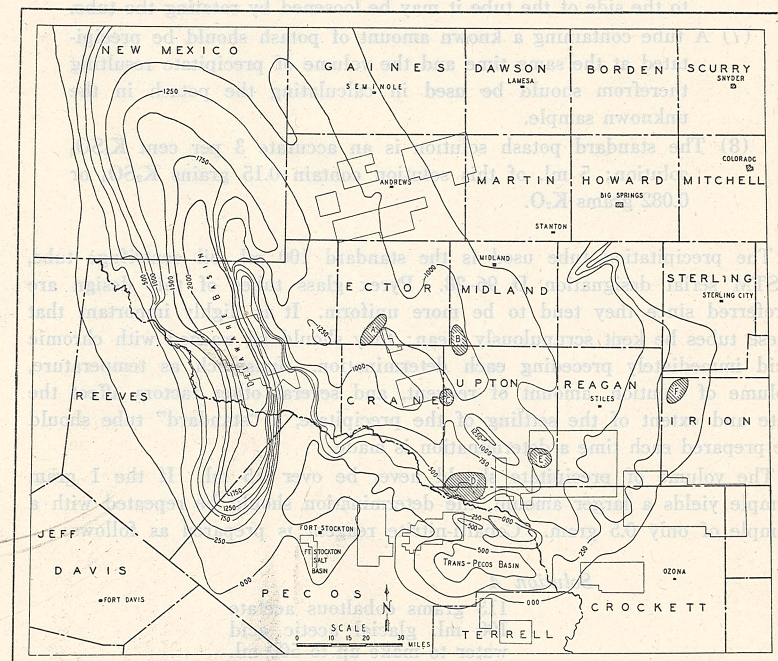

Fig. 35. Map showing thickness of the upper salt of the Permian basin. Contributed by J. N. Gregory, Geologist, University Lands Survey. See Figure 37 for names of the polyhalite areas A to F designated on this map.

basin. The cross-hatched portions represent areas in which the best indications of commercial polyhalite strata were found. Figure 36 shows the total thickness of the salt, including upper and lower salt strata. Figure 37, adapted from a map prepared by H. P. Bybee,

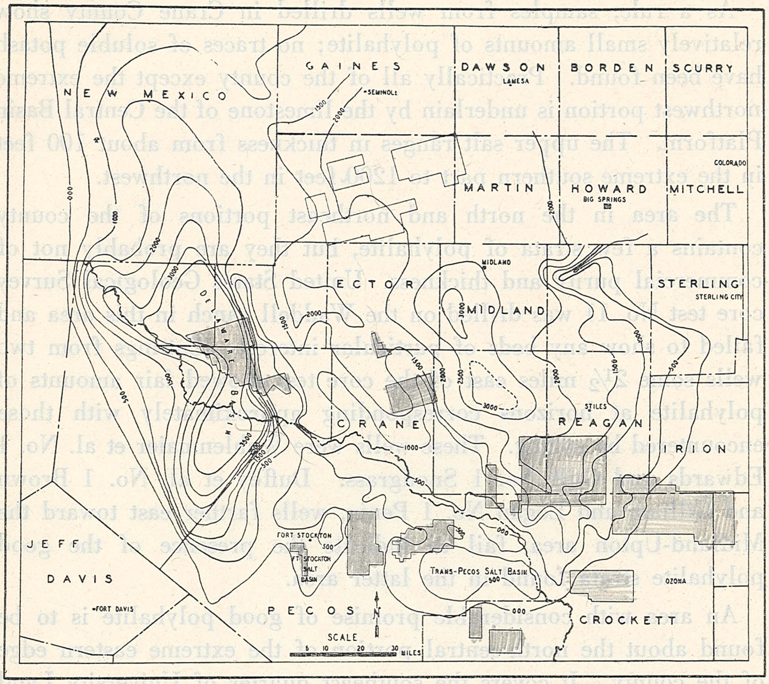

Fig. 36. Map showing combined thickness of upper and lower salt of Permian basin. Contributed by J. N. Gregory, Geologist, University Lands Survey.

indicates the relation of the potash to major structural features. So far as known, the potash salts are confined to the upper salt horizons.

SUMMARY OF RESULTS

It is impossible to list in detail all the data obtained in this study. Hence there is given below a summary of the information obtained.

ANDREWS COUNTY

Although Andrews County lies wholly within the salt basin and has an upper salt thickness ranging from 750 to 1500 feet, so far as known it contains no promising strata of polyhalite. Those which are found are small and are so deep that they can not be considered as having commercial possibilities at the present time.

CRANE COUNTY

As a rule, samples from wells drilled in Crane County show relatively small amounts of polyhalite; no traces of soluble potash have been found. Practically all of the county except the extreme northwest portion is underlain by the limestone of the Central Basin Platform. The upper salt ranges in thickness from about 100 feet in the extreme southern part to 1200 feet in the northwest.

The area in the north and northeast portions of the county contains a few strata of polyhalite, but they are probably not of commercial purity and thickness. United States Geological Survey core test No. 11 was drilled on the Waddell ranch in this area and failed to show any beds of particular interest. Cuttings from two wells some 2½ miles east of the core test showed fair amounts of polyhalite at horizons corresponding approximately with those encountered by coring. These wells were Wahlenmaier et al. No. 1 Edwards and Gulf No. 1 Snodgrass. Duffey et al. No. 1 Brown and Gilliam and Logan No. 1 Penix, wells farther east toward the Midland-Upton area, fail to indicate the presence of the good polyhalite strata found in the latter area.

An area with considerable promise of good polyhalite is to be found about the north-central portion of the extreme eastern edge of the county. It covers the southeast quarter of University Land Block 30 and the Crier-McElroy area immediately south of Block 30 in Crane and Upton counties. Here there appears to be a polyhalite stratum about 100 to 200 feet below the top of the salt which may be of commercial importance. "High-graded" samples of the polyhalite taken from the cuttings tested as high as 16.3 per cent K_2O, thus indicating possible enrichment. However, it is probable that this enrichment was due to evaporation of drilling water which contained some dissolved potassium.

Oil, gas, power, water, and a hard-surfaced highway are close at hand. However, the production of polyhalite in this area would be seriously handicapped by the isolation from a railroad and by the production of oil from strata underlying the polyhalite. The nearest railroad is the Santa Fe at McCamey, which is about 22 miles southeast. Much oil has been and is now being produced from this area, and it is possible that gas leakages through faulty casing seats or breaks in the casing would prove to be a very serious problem in event potash mining should be started.

It has been reported that much polyhalite was encountered in the southern portion of the county when the Dixie Oil Company was drilling core wells to locate the top of the "big lime." Unfortunately, both cores and records of these wells were destroyed. Samples from two cable tool wells drilled in this area do not show enough polyhalite to create interest.

CROCKETT COUNTY

The northwest one-third of Crockett County lies within the salt basin, and the thickness of the upper salt ranges up to about 750 feet. The area has been well prospected for oil, but relatively few complete strings of salt samples are available. Two United States Geological Survey core tests were drilled in the county, but neither encountered potash beds of commercial importance. Samples of the cuttings from cable tool wells near the core wells also fail to indicate any worthwhile potash beds.

The extreme northwest portion of the county has better indications of the presence of a good bed of polyhalite than any other area in the county. In the Taylor-Link Oil Company No. 1 L. C. Peck, the top of the salt is at 370 feet and a good polyhalite bed was encountered at 410–30 feet. The sample from 412–30 feet tested 10.9 per cent K_2O; no "high-graded" sample was run because the original sample was too small. The Tidal Oil Company No. 1 Weatherred, approximately 4 miles west of the Taylor-Link No. 1 Peck, has good polyhalite shows in the corresponding horizon, which is there about 100 feet lower than in the latter well.

The area in which it is possible that commercial polyhalite will be found is traversed by good highways and power lines. The nearest railroad is the Santa Fe at McCamey which is about 9 miles north; both gas and fuel oil are to be had within a few miles. Shaft sinking and mining should be relatively simple—the depth is not great, no water-bearing horizons of any importance are likely to be encountered, and the anhydrite and salt above the polyhalite should provide a good mine roof which would not require timbering.

No indications of soluble potash have been found in Crockett County.

DELAWARE BASIN

The Texas portion of the Delaware basin occupies the western part of Pecos County, all of Reeves and Loving and the western portions of Ward and Winkler counties. In New Mexico the basin occupies the eastern portion of Eddy County and the western half of Lea County. It is characterized by a very thick salt section, the upper salt reaching approximately 2500 feet as its maximum thickness. The western slope of the basin is very gentle, but the eastern slope rises abruptly against the Central Basin Platform.[14] The

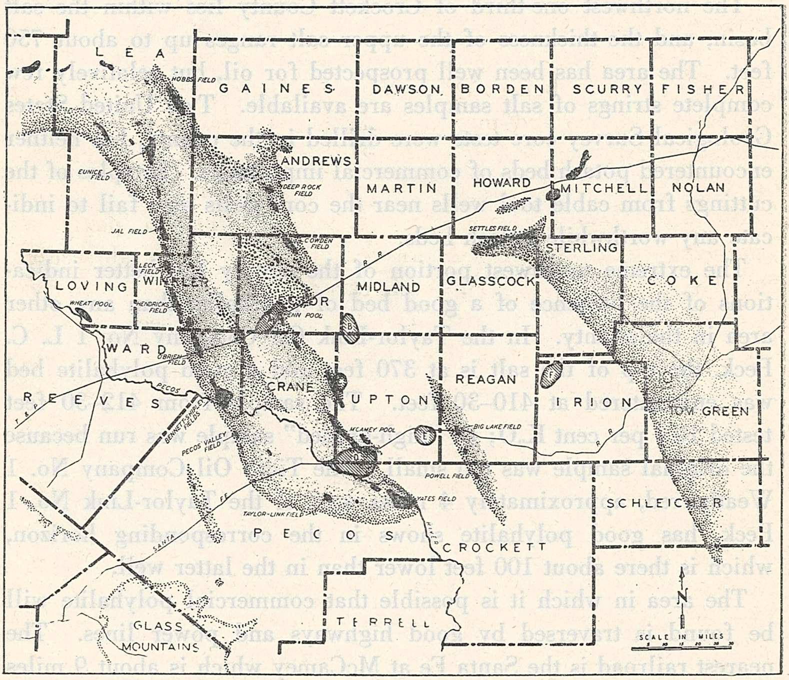

Fig. 37. Map showing relation of known polyhalite areas to the major structural features of west Texas. A, Connell area; B, Jones area; C, Crier-McElroy area; D, McCamey area; E, Bell-Regan area; F, Suggs area. The oil fields of this region are shown in black.

[14]Bybee, H. P., Some major structural features of west Texas: Univ. Texas Bull. 3101, pp. 19–26, 1931.

thickest salt deposits are in the eastern portion of the basin, in central Ward, western Winkler and eastern Loving counties, and on up into southwestern Lea County, New Mexico.

The New Mexico portion of the Delaware basin has been extensively prospected for potash by core drilling. At least two good deposits of sylvinite have been located and are being mined at the present time. The United States Potash Company, the pioneer company, has two shafts in operation and the Potash Company of America has one shaft. Several hundred core wells have been drilled, but these are the only two companies which have actually opened up commercial deposits. Although sylvinite is the only mineral now being mined, smaller deposits of carnallite, langbeinite and polyhalite have been cored. No attempt is being made to mine these latter minerals.

The Delaware basin has seen very little drilling south of the Texas-New Mexico boundary. Two United States Geological Survey core tests were drilled in the basin, No. 12 in extreme western Winkler County and No. 18 in eastern Loving County. The Winkler County well is particularly interesting. Approximately 1500 feet of the salt section were cored and no polyhalite beds of particular significance were encountered. In the upper part of the salt section, namely, 1243 to 1796 feet, much carnallite was found. No one seam was over an inch in thickness and in no one section of the core does it constitute more than half the core recovered. However, the fact that carnallite was found scattered through such a long interval, 553 feet, shows very clearly that much dissolved potassium was present in the residual brines at the time the salt was being deposited. Polyhalite, langbeinite, keiserite, and sylvite were also found in this same interval.

The Loving County core test was located very nearly in the middle of the basin. The first salt was encountered at about 1215 feet and only 665 feet of the salt section was cored. The portion cored, however, correlates very well with the same section of the Winkler County well except for the fact that it does not have the wide distribution of carnallite. However, some sylvite and polyhalite were found in the same horizons in both wells. It is to be regretted that this test was not cored at least 300 or 400 feet deeper into the salt, because, according to some correlations, the horizons from which sylvinite is now being mined in New Mexico lie immediately below the point at which coring was stopped.

Such samples as are available from wells drilled in the basin are very unsatisfactory from the standpoint of indicating the presence of soluble potash minerals. As a general rule the salt samples were taken over rather long intervals and hence were subject to much dissolution. The wells are also so widely scattered that definite correlation is very uncertain.

The Delaware basin is undoubtedly the area in Texas in which the search for soluble potassium minerals is most promising. Sylvinite is already being mined in the New Mexico portion of the basin and deposits of carnallite and langbeinite in possible commercial thicknesses have been reported. The two core tests in the Texas portion of the basin showed some sylvite and carnallite—No. 12, in Loving County, contained carnallite scattered throughout a longer interval than did any other well drilled in the basin. The New Mexico deposits are on the edge of the basin; both the Texas core tests were in or near the deepest portion of the basin. United States Geological Survey core test No. 14, which is some 6 or 7 miles nearer the eastern edge than is No. 18, is the one which showed the widely disseminated carnallite. No wells have been drilled on Texas locations corresponding to those of the New Mexico deposits. Hence the possibilities of a soluble potash deposit in Texas must not be underestimated.

University of Texas Blocks 16, 17, 18, 19, 20, and 21 in Loving, Winkler and Ward counties, lie wholly or partially within the potential soluble potash area of the Delaware basin. This land has the decided advantages of (1) having some 125 square miles covering about 20 miles along the eastern edge and extending well into the middle of the basin; (2) being all under one ownership; (3) being traversed by the main line of the Texas & Pacific Railroad from Big Spring to El Paso; (4) having water, fuel, and power available within a reasonable distance.

ECTOR COUNTY

Ector County probably has a greater area containing potentially commercial polyhalite deposits than any other county in west Texas. Its nearest rival in this respect is Upton County. The county contains a fairly well defined limestone reef which underlies approximately all except the eastern one-third of the county. The entire county lies within the salt basin, the thickness of the upper salt ranging from 850 to 1250 feet. Odessa, the county seat and the only town, is in the central-eastern portion of the county on the Texas & Pacific Railroad.

One core test, United States Geological Survey No. 4, was drilled in the southwest part of the county, about 2½ miles southwest of Judkins. This well encountered a better showing of polyhalite than any other United States Geological Survey core well drilled in Texas. At least two potentially mineable deposits were penetrated, one at 1303–12 feet and another at 1935–45 feet. Both of the above intervals contained two very good polyhalite strata separated by beds of salt and anhydrite.

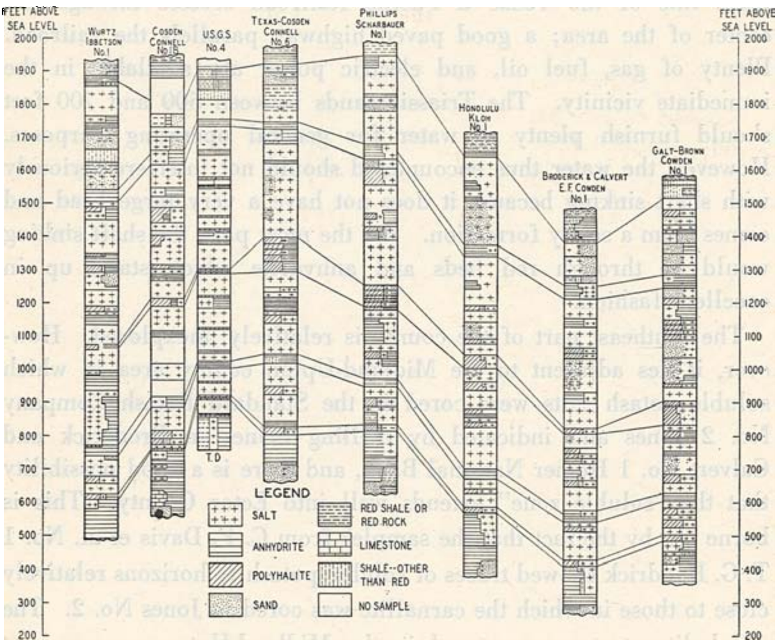

Fig. 38. Section through the upper salt in the Connell area, south-central Ector County.

The general area from United States Geological Survey core test No. 4, thence northeast through Judkins and north of the Penn pool has excellent indications of the presence of polyhalite beds which may be produced commercially. The correlation of the strata through this area is shown in the section in Figure 38. Two wells shown in this section are particularly interesting, namely, Texas-Cosden No. 6 Connell and Phillips No. 1 Scharbauer. In the former, six samples were taken over the 100-foot interval 1475–1575 feet, the average K_2O content of the samples being 9.25 per cent. In the corresponding horizon in the latter well, six samples were taken over the 75-foot interval 1675–1750 feet which had an average K_2O content of 9.1 per cent. These two wells are 3 miles apart, and it is logical to assume that at some place in this interval of high K_2O content there is a polyhalite bed of such a purity and thickness that it can be mined economically.

General conditions for mining in this area are very good. The main line of the Texas & Pacific Railroad crosses through the center of the area; a good paved highway parallels the railroad. Plenty of gas, fuel oil, and electric power are available in the immediate vicinity. The Triassic sands between 500 and 700 feet should furnish plenty of water for general operating purposes. However, the water thus encountered should not interfere seriously with shaft sinking because it does not have a very large head and comes from a sandy formation. For the most part, the shaft sinking would be through red beds and anhydrite which stand up in excellent fashion.

The southeast part of the county is relatively unexplored. However, it lies adjacent to the Midland-Upton county area in which soluble potash salts were cored in the Standard Potash Company No. 2 Jones and indicated by drilling brines in Broderick and Calvert No. 1 Homer National Bank, and there is a good possibility that the "soluble zone" extends well into Ector County. This is borne out by the fact that the samples from C. P. Davis et al. No. 1 T. G. Hendrick showed traces of soluble potash in horizons relatively close to those in which the carnallite was cored in Jones No. 2. The polyhalite strata encountered in the Midland-Upton area are not well defined in the few wells drilled in southeast Ector County. It should be noted that should either sylvite, carnallite, or polyhalite be found in commercial quantities in this area, shaft sinking might prove rather difficult because of the water to be encountered. All wells drilled in this area have penetrated sands which contained water in rather large quantities. Although a surfaced highway traverses the territory, railroad, fuel, and power lines are from 5 to 20 miles distant.

GLASSCOCK COUNTY

Approximately three-fourths of Glasscock County lies within the area in which salt is found, and the thickness of the upper salt ranges up to some 700 feet. There are a number of good sets of salt section samples from Glasscock County available for examination. However, very little potash was found in the samples.

The United States Geological Survey potash test No. 10 was drilled in the southwest quarter of the northeast quarter of Section 14, Block 35, T. 2 S., Texas & Pacific Railroad Survey. This well encountered some six or seven strata of polyhalite ranging from a few inches to 1 foot 4 inches in thickness and containing up to 15.12 per cent K_2O. At two points, approximately 1370 and 1552 feet, kieserite ($MgSO_4.H_2O$), was encountered in small amounts. This is of some significance because of the fact that it is possible for both carnallite and kainite to exist in the presence of kieserite, which indicates that these latter minerals might exist somewhere in this locality. Because of their great solubility, well cuttings would probably give no indication of the presence of these minerals. Good correlation between a core test and cuttings from a cable tool well is afforded in Glasscock County by the proximity of United States Geological Survey core test No. 10 to the Landreth Production Company No. 2 Houston, which is in the southeast corner of Section 18 of the same block in which the core test is located. Graphical comparison of the two wells is shown by the plotted logs in Figure 39. It should be recognized, of course, that the regularity of the appearance of the six polyhalite strata in both of these wells in such "text-book" fashion is not always encountered. However, it does indicate that well cuttings can be used to obtain qualitative indications of the presence of polyhalite, but that they do not furnish reliable data on which to base an estimate of the probable thickness of the stratum from which the cuttings are obtained.

Visual examination of the cuttings will probably enable the careful observer to arrive at some idea concerning whether polyhalite is intermixed with halite and anhydrite or whether it exists as a separate stratum.

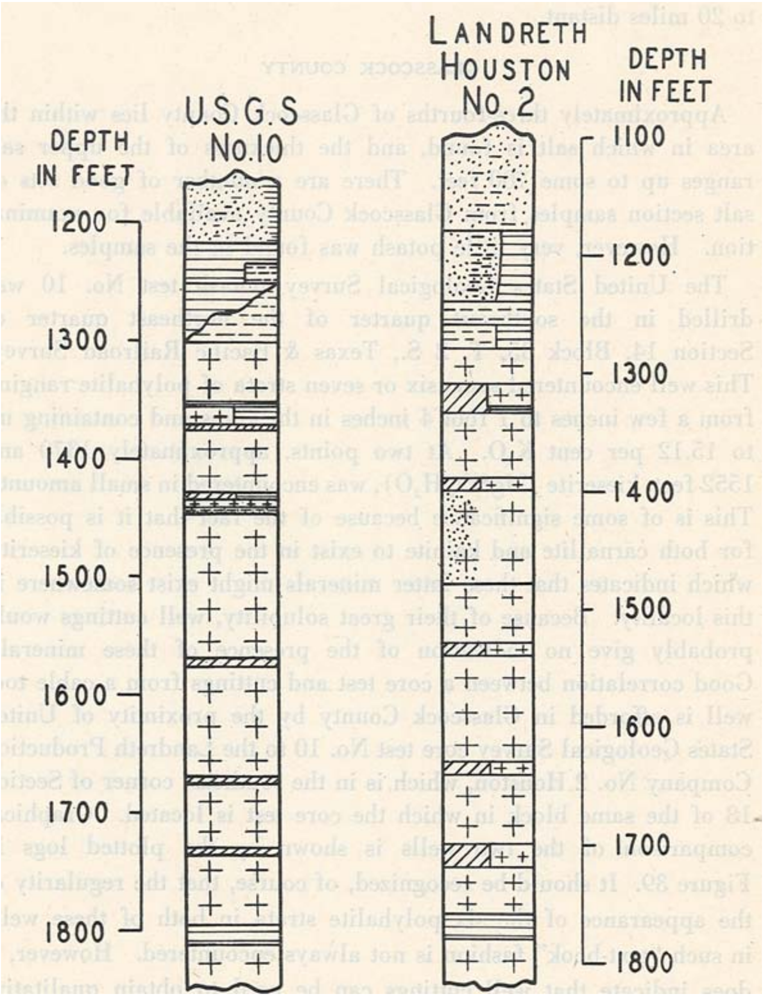

Fig. 39. Correlation between log of a United States Geological Survey core test and that made by examination of cuttings from a nearby cable tool well. Legend same as for Figure 38.

IRION COUNTY

The north and central-west portions of Irion County lie within the boundary of the salt basin, and the maximum salt thickness encountered is approximately 200 feet. However, there is fair evidence that there is a good deposit of polyhalite in the northwestern portion of the county. The extent of the deposit is, of course, unknown, but its depth is only approximately 800 to 900 feet. It was in a well in this area, Fuhrman Petroleum Company No. 1 J. D. Sugg, that the richest sample obtained in this entire investigation was found. The samples from 844–58 feet tested 13.9 per cent K_2O, which corresponds to approximately 90 per cent pure polyhalite.

Despite the apparent richness of the deposit, the area has several disadvantages with respect to the mining of polyhalite. The nearest railroad is approximately 25 miles away and sources of fuel and electric power are even farther. The general topography is rather rough and any shaft sunk in this area would probably encounter several water horizons in the 200 or more feet of sand which must be penetrated.

MIDLAND COUNTY

Midland County lies in the approximate center of the basin and contains no known large structural feature; hence relatively few wells have been drilled in this county. Of ten wells which have been drilled in the county, two were core wells drilled in 1925, 1926, and 1927 by the Standard Potash Company, now the Texas Potash Corporation of Texas, on the O. P. Jones ranch in the extreme southwest part of the county. The second of these wells cored approximately 6 feet of soluble potash between 1975 and 1990 feet. Much of the core was lost but sufficient sample was obtained for analysis. Sellards and Schoch[15] state that the soluble salts were chiefly carnallite, kainite, and kieserite. Other soluble minerals were present in smaller amounts. Well No. 1 was drilled below the soluble layer before the anti-solvent solution was used; hence no core was obtained. However, a large increase in the potash content of the drilling water indicated that the soluble layer was encountered. Cuttings from two cable tool wells drilled in the county, namely,

[15]Sellards, E. H., and Schoch, E. P., *op. cit.*

Atlantic, Cope & Shelton No. 1 Kloh and Nordon & Kirvin No. 1 Mathena, showed traces of soluble potash in horizons corresponding approximately to the soluble layer in Standard Potash Company No. 2 Jones.

In addition to the soluble potash, all wells have encountered much polyhalite. Standard Potash Company No. 1 Jones recovered a 5-foot core of practically pure polyhalite having the following composition:[16]

	Per Cent
K_2O	15.04
CaO	24.42
MgO	6.56
SO_3	48.55
H_2O	4.67
$NaCl$	0.76
	100.00

The corresponding stratum in Jones No. 2 was 3½ feet thick. Cuttings from both the cable tool wells mentioned above indicate good beds of polyhalite at the corresponding horizons.

PECOS COUNTY

As shown on the map (fig. 35) the south and central portions of Pecos County do not lie within the salt-bearing area. The territory around the Yates oil field in eastern Pecos County also constitutes an "island" containing no salt. The extreme western part of the county lies within the Delaware basin and contains salt ranging up to 1800 feet in thickness.

Although there appears to be no important polyhalite deposits in the county there are two structural features of considerable interest from the standpoint of potential potash deposition. These have been designated the Trans-Pecos Salt basin and the Fort Stockton Salt basin. Both of these appear to be in the nature of cut-off basins in which considerable thicknesses of salt have been deposited; theoretically ideal conditions for the deposition of potash minerals.

The Trans-Pecos Salt basin includes most of the southeast portion of Pecos County. The upper salt in this basin ranges up to 650 feet in thickness. Fairly good samples are available from wells

[16]*Idem*, p. 123.

drilled in the basin but none of them indicates polyhalite beds of sufficient thickness and purity to be of particular interest. There appear to be about six thin polyhalite strata in the salt section indicating as many periods of fill and evaporation. No traces of soluble potassium salts were encountered.

The Fort Stockton Salt basin is much smaller than the Trans-Pecos Salt basin and lies east and northeast of the city of Fort Stockton. Upper salt thickness ranges up to 750 to 800 feet. Samples from two wells, Pinal Dome No. 1 Devlin and Buell and Hagan No. 1 Pryor-Wilson, show only a small amount of polyhalite and no traces of soluble potash minerals.

The remaining portion of Pecos County which lies within the salt basin is not known to contain potash beds of particular interest. Drillers have reported much potash in the area west of Imperial and south of the eastern part of Ward County, but it has not shown up in the samples from wells drilled in the area.

UPTON COUNTY

Upton County lies entirely within the salt basin, the upper salt ranging from 500 to 1300 feet in thickness. Although the Central Basin Platform crosses the extreme west and southwest portions, the county lies principally in the basin. In fact, one well, Hultz et al. No. 1 Halff, encountered 1280 feet of upper salt which is more than that found in any other well east of the Central Basin Platform. Hence the county has relatively favorable conditions for the occurrence of soluble potash.

Unfortunately, no reliable salt samples are available from the early wells drilled in the basin. Two United States Geological Survey core tests were drilled in the southwestern part of the county, No. 6 on the Burleson lease and No. 7 on the Hughes-Roxana lease. Both of these wells were drilled on the Central Basin Platform and hence furnish no data concerning the basin area. Cuttings from a number of wells drilled off this limestone "high" indicate much better polyhalite beds than do the wells adjacent to these core tests.

In the extreme northwestern portion of the county two wells, Skelly Oil Company No. 1 Jones and Broderick & Calvert No. 1 Homer National Bank, are within 4 or 5 miles of the two core tests drilled in Midland County by the Standard Potash Company.

Cuttings from both of the wells show good polyhalite strata at horizons corresponding to the 5-foot bed cored at 2176–81 feet in the first core well. Samples of the drilling water were saved from the upper portion of the salt section encountered in Broderick & Calvert No. 1 Homer National Bank and tested for dissolved potassium. Results are given below:

Interval Feet	Gms. K_2SO_4 Per Liter	Interval Feet	Gms. K_2SO_4 Per Liter
1800–1810	00	2037–2050	19.7
1810–1825	00	2050–2065	9.9
1825–1835	00	2065–2085	11.8
1835–1845	00	2080–2095	15.8
1845–1857	00	2095–2108	15.0
1857–1875	00	2108–2124	11.8
1875–1892	1.9	2124–2140	8.2
1892–1905	00	2140–2155	3.6
1905–1920	00	2155–2171	2.8
1920–1930	3.0	2171–2190	15.0
1930–1945	2.6	2190–2200	11.8
1945–1957	3.9	2200–2212	11.8
1957–1970	3.9	2212–2222	20.7
1970–1983	2.0	2222–2228	20.7
1983–1995	2.8	2228–2240	25.0
1995–2015	3.2	2240–2252	17.8
2015–2026	15.0	2252–2265	17.8
2026–2037	15.0	2265–2280	15.7

The sharp increase in potash at 2015–50 feet is at a point corresponding with the horizon in which approximately 6 feet of carnallite and other soluble potassium salts were found in Jones No. 1 core well. The cuttings from this horizon contain no polyhalite but consist of white, porous, crystalline anhydrite mixed with a small amount of salt and gray shale. Chemical tests show that definite traces of soluble potash are present in cuttings. The interval 2080–2108 feet shows a relatively high potash content in the brine which may have been occasioned by "salting" from the soluble beds above or by the presence of small amounts of polyhalite or by the presence of another bed of more soluble potassium. A second soluble potash zone was not encountered in either of the two core tests.

Another radical increase in the potash in the brine was noted in the samples throughout the interval 2212–80 feet. This was undoubtedly due to the presence of large amounts of polyhalite in this horizon which corresponds to the main polyhalite stratum encountered in the core wells.

Two wells, Sartain Bros. and Davis No. 1 Bull and Penn-Shell No. 1 Halamicek, 10 and 14 miles, respectively, southeast of Skelly No. 1 Jones, show both the anyhdrite adjacent to the soluble salts horizon and the main polyhalite zone encountered in the Jones area. The salt section thins to the southeast and the strata are approximately 450 feet nearer the surface in Penn-Shell No. 1 Halamicek than in Standard Potash Company No. 2 Jones. The dip appears to be uniform.

One well, Gulf Production Company No. 9 Crier-McElroy, on the extreme central-west edge of the county had a good showing of polyhalite at approximately 1300 feet. One sample taken at 1280–1315 feet tested 12.3 per cent K_2O. The polyhalite was apparently well separated from the salt and anhydrite and a "high-graded" sample tested 15.5 per cent K_2O. Samples from adjacent wells were not available for checking the extent of this bed.

The southwest quarter of the county contains a well developed oil producing structure in the limestone. The top of the structure has been extensively drilled and good samples are available for study. United States Geological Survey core tests Nos. 6 and 7 were drilled on top of the structure. Several strings of samples of wells drilled on the flanks of structure are available. These wells show very good polyhalite strata and indicate the presence of much better polyhalite beds than do the samples from wells in the immediate vicinity of the United States Geological Survey core wells. This general area has the advantages of a relatively shallow depth to the salt and polyhalite and of being close to railroad transportation.

In the south-central and eastern parts of the county the top of the salt is deeper, ranging to about 1250 feet. Few wells have been drilled in these areas and samples are available on approximately 50 per cent of those drilled. Only five or six samples were saved from the salt section in Virginia Petroleum Company No. 1 University. However, two samples, 1355–80 feet and 1380–95 feet, contained much polyhalite.

Bell & Regan No. 1 Flatrock, on University-owned land, is one of the most interesting wells in the entire basin from the standpoint of potash possibilities. The well is located about 5 miles east of

Rankin and is within half a mile of the Santa Fe Railroad. Top of the salt is at 1220 feet and the upper salt is about 830 feet thick. The sample from 1235–50 feet showed, chemically, a trace of soluble potassium salts, and several blue salt crystals were found by visual examination. These blue salt crystals are found in the sylvite area of New Mexico where they are considered to be indicative of the presence of soluble potassium salts. The source of the blue color is somewhat indefinite, though it has been explained as being due to finely dispersed metallic potassium produced by reduction of potassium chloride by organic matter. Hence, with these two indications of the presence of soluble potassium minerals, it is possible that either carnallite or sylvinite is present in this horizon.

In addition to the soluble potash possibilities, this well also encountered an excellent showing of polyhalite at 1540–65 feet. Two samples, 1540–52 and 1552–65 feet, tested 9.8 and 6.8 per cent K_2O, respectively; "high-graded" material tested 15.6 and 13.7 per cent. In general, the fragments of polyhalite appeared to be well segregated from the salt. If the "high-graded" sample is assumed to be representative of the polyhalite stratum and if the original sample is representative of the formations drilled during this interval, the ratio of the K_2O contents indicates a stratum some 14 feet thick. However, such unusual thickness is not to be expected since both of the above assumptions are subject to question.

The geographical location of this well is very good. Highway, railroad, power, water, and fuel are available. All land in the immediate vicinity belongs to one owner, The University of Texas. The only disadvantage is the depth, which would increase materially the cost of coring and shaft sinking.

RELATION OF THE PRINCIPAL POLYHALITE ORES TO REGIONAL STRUCTURAL FEATURES

The name and chemical composition of some of the more common potash and associated minerals are given in the following table:[17]

[17]For a concise description and list of properties of the minerals listed, see Grabau, A. W., Geology of the Nonmetallic Mineral Deposits Other than Silicates, pp 29–39, McGraw-Hill Book Company, New York, 1920.

Anhydrite	$CaSO_4$
Bischofite	$MgCl_2.6H_2O$
Carnallite	$KCl.MgCl_2.6H_2O$
Epsomite	$MgSO_4.7H_2O$
Glaserite	$KNaSO_4$ or $K_3Na(SO_4)_2$
Glauberite	$Na_2SO_4.CaSO_4$
Gypsum	$CaSO_4.2H_2O$
Halite (rock salt)	$NaCl$
Kainite	$KCl.MgSO_4.3H_2O$
Kieserite	$MgSO_4.H_2O$
Krugite	$K_2SO_4.MgSO_4.4CaSO_4.2H_2O$
Langbeinite	$K_2SO_4.2MgSO_4$
Leonite	$K_2SO_4.MgSO_4.4H_2O$
Pentasalt	$5CaSO_4.K_2SO_4.H_2O$
Polyhalite	$K_2SO_4.MgSO_4.2CaSO_4.2H_2O$
Schönite	$K_2SO_4.MgSO_4.6H_2O$
Sylvinite	XNaCl.Y KCl (a eutectic mixture of halite and sylvite)
Sylvite	KCl
Syngenite	$K_2SO_4.CaSO_4.H_2O$

The most generally accepted theory concerning the mode of formation of the Permian potash deposits is that they are evaporites laid down by the evaporation of brine concentrates of a cut-off arm of the sea. Under this hypothesis it is assumed that the potassium salts, since they are usually quite soluble, were gradually concentrated in the deepest and last existing depressions or basins, and that potassium salts are most likely to be encountered in the middle of the basin and in the thickest salt sections. The results of this investigation indicate that the areas in which polyhalite is most abundant are not in accordance with the above theory, since, with only one apparent exception, the best polyhalite areas thus far discovered are found near the rim of the salt basin or near the edges of limestone structures. Present indications point to the fact that the area in southwest Midland County in which the Texas Potash Corporation drilled its Jones core wells, the apparent exception referred to above, may not be an exception after all. Although the regional dip is to the east, the strata in the two Jones wells dip to the west. This fact, combined with data from oil tests drilled in the area, indicates the presence of a small structural feature nearby, though the extent and exact location are as yet undetermined—hence the term apparent exception used above.

Contrary to general opinion, a high concentration of potassium in solution is not essential to the formation of polyhalite. International

Critical Tables, Volume IV, page 349, gives the following data on the system $SO_4^{=}$, Mg^{++}, Ca^{++}, K^{+} (H_2O—$MgSO_4$—$CaSO_4$—K_2SO_4), at a temperature of 25° C.

Table Showing Phase Relationships of Ca^{++}, Mg^{++}, K^{+}, $SO_4^{=}$, and H_2O at 25° C.

	Solid Phases	*Liquid Phases* $CaSO_4$ Per cent	$MgSO_4$ Per cent	K_2SO_4 Per Cent
A	$MgSO_4.7H_2O + CaSO_4.2H_2O$	?	26.82	----
B	$MgSO_4.7H_2O$	----	26.76	----
C	$K_2SO_4 + CaSO_4.K_2SO_4.H_2O$	?	----	10.40
D	K_2SO_4	----	----	10.77
E	$CaSO_4.2H_2O + CaSO_4.K_2SO_4.H_2O$	0.18	----	3.09
F	$MgSO_4.7H_2O + MgSO_4.K_2SO_4.6H_2O$	----	26.39	4.02
G	$K_2SO_4 + MgSO_4.K_2SO_4.6H_2O$	----	12.68	10.70
P	$K_2SO_4 + MgSO_4.K_2SO_4.6H_2O + CaSO_4.K_2SO_4.H_2O$	?	11.35	11.89
	$MgSO_4.7H_2O + MgSO_4.K_2SO_4.6H_2O + CaSO_4.K_2SO_4.H_2O$	?	27.05	3.56
R	$CaSO_4.2H_2O + CaSO_4.K_2SO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	26.36	2.39
	$MgSO_4.7H_2O + CaSO_4.K_2SO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	27.02	3.43
	$MgSO_4.7H_2O + CaSO_4.2H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	26.47	2.48

At 83° C. the phase relationships for the same system are as follows:

Table Showing Phase Relationships of Ca^{++}, Mg^{++}, K^{+}, $SO_4^{=}$, and H_2O at 83° C.

	Solid Phases	*Liquid Phases* $CaSO_4$ Per Cent	$MgSO_4$ Per Cent	K_2SO_4 Per cent
A	$MgSO_4.H_2O + CaSO_4$	—	40.20	—
B	$MgSO_4.H_2O$	—	40.20	—
C	$2MgSO_4.K_2SO_4 + MgSO_4.H_2O$	—	37.04	1.78
D	$K_2SO_4 + MgSO_4.K_2SO_4.4H_2O$	—	18.56	16.12
E	$K_2SO_4 + CaSO_4.K_2SO_4.H_2O$	?	—	17.88
F	$CaSO_4.K_2SO_4.H_2O + 5CaSO_4.K_2SO_4.H_2O$	?	—	8.82
G	$CaSO_4 + 5CaSO_4.K_2SO_4.H_2O$	?	—	1.19
P	$5CaSO_4.K_2SO_4.H_2O + CaSO_4 + 4CaSO_4.MgSO_4.CaSO_4.2H_2O$	?	4.03	3.15
Q	$5CaSO_4.K_2SO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O + 4CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	5.12	4.80
R	$CaSO_4.K_2SO_4.H_2O + 5CaSO_4.K_2SO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	2.68	8.00
S	$K_2SO_4 + CaSO_4.K_2SO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	15.48	15.39
T	$K_2SO_4 + MgSO_4.K_2SO_4.4H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	18.56	16.12
U	$MgSO_4.K_2SO_4.4H_2O + 2MgSO_4.K_2SO_4 + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	28.51	7.86
V	$2MgSO_4.K_2SO_4 + MgSO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	37.03	1.78
W	$MgSO_4.H_2O + 2CaSO_4.MgSO_4.K_2SO_4.2H_2O + 4CaSO_4.MgSO_4.K_2SO_4.2H_2O$	?	38.48	0.29
Y	$2MgSO_4.K_2SO_4 + MgSO_4.K_2SO_4.4H_2O$		36.36	7.85

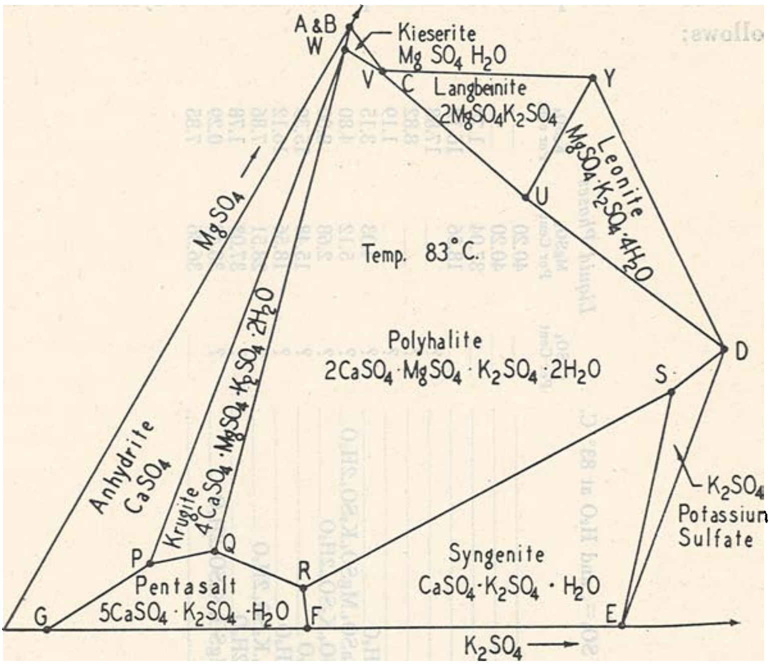

Fig. 40. Phase diagram for the system $SO_4^{=}$, Mg^{++}, Ca^{++}, K^+ (H_2O — $MgSO_4$ — $CaSO_4$ — K_2SO_4) at 83° C.

The phase diagram for the system at 83° C. is shown in Figure 40. In this diagram, the enclosed areas represent concentrations of the solution at which it is in equilibrium with the one constituent, the boundary lines represent concentrations at which the solution is in equilibrium with the constituents on each side of the line, and the nonvariant points represent concentration at which the solution is in equilibrium with all solids adjacent to that point.

These data show that polyhalite can be precipitated from a solution having a potassium sulfate concentration ranging from 0.29 to 16.12 per cent at 83° C. Although there are no data available for temperatures between 25° C. and 83° C., it is logical to assume that the concentration range at which polyhalite would be precipitated at "normal" temperatures, *i.e.*, 30° C. to 50° C., is probably 1.5 to 10 per cent. Any gypsum or anhydrite in contact with a solution of appropriate concentrations of potassium sulfate and magnesium sulfate would also tend to be slowly dissolved and re-precipitated as polyhalite.

After a rather intensive mineralogical study of cores and cuttings from wells drilled in Texas and New Mexico, Schaller and Henderson[18] came to the conclusion that, while some polyhalite was undoubtedly formed by direct precipitation from brines, most of it has been derived from preëxisting minerals by the action of natural brines or solutions. Such a conclusion appears quite logical from the standpoint of the solubility of the individual constituents of polyhalite if it is remembered that "replacement" in this case probably means the complete dissolution of one mineral and the precipitation of polyhalite, though not necessarily as a pseudomorph after the original mineral. The major constituent of polyhalite is calcium sulfate which constitutes over 45 per cent of the more complex mineral. Since both anhydrite and gypsum are soluble to the extent of only about 0.2 per cent, the precipitation of only a relatively small amount as polyhalite would remove all available calcium sulfate from solution. If, then, the magnesium and potassium sulfate concentration of the brine is such that it is in equilibrium with polyhalite and not with anhydrite or gypsum, the latter will tend to be dissolved and the former precipitated continuously.

The greater prevalence of polyhalite near the edge of the salt basin and in the vicinity of the pronounced structures in the underlying limestone instead of in the middle of the basin may be further evidence of the secondary formation of polyhalite. Calcium sulfate carried in solution by the fresh water streams entering a large body of salt water will tend to be precipitated near the point of entrance. As the concentration of potassium and magnesium sulfates in the brine increases, the anhydrite or gypsum previously deposited will tend to be dissolved and re-precipitated as polyhalite. The incoming calcium sulfate might well be dissolved and re-precipitated as polyhalite in its passage through the brine and be initially deposited as polyhalite. Such action in itself would constitute replacement, though not *in situ*. Whatever the mode of formation, it appears quite evident that the proximity of the land masses which serve as

[18]Schaller, W. T., and Henderson, E. P., Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Geol. Surv., Bull. 833, pp. 50–73, 1932.

a source of calcium sulfate might explain the prevalence of polyhalite in the "shallower" portions of the basin.

Several factors which are not in full accord with the replacement theory should not be overlooked. There is much anhydrite scattered throughout the basin which was undoubtedly in contact with the potassium and magnesium sulfate brine but which does not contain any appreciable quantities of polyhalite. On the other hand, there is much polyhalite in the basin which is not closely associated with anhydrite. This might have resulted from the displacement of other minerals such as glauberite, halite, kieserite, or leonite, but it appears quite probable that much of it might be polyhalite of primary deposition. Each influx of fresh water carrying calcium sulfate in solution would tend to spread a "layer" of fresh water on top of the denser brine, the calcium sulfate later being precipitated as the two strata of water were mixed by diffusion. This precipitated calcium sulfate in passing through the brines to the bottom could be transformed to polyhalite quite readily and deposited directly as that mineral. This theory of primary precipitation is substantiated by the facts that at least two strata of polyhalite near the base of the upper salt are practically continuous over the entire basin and that many strata of polyhalite are closely associated with sand and shale but not with anhydrite. Hence it appears that the polyhalite of the Permian basin is of both primary and secondary origin and that the proximity of the land masses from which the calcium sulfate was derived accounts for the greater concentrations of polyhalite near these land masses, regardless of its mode of formation.

There is yet another problem, the solution of which is very uncertain. Upon the removal of polyhalite from the brines there must have remained a rather high concentration of magnesium sulfate in the residual brines. So far, no extensive deposits of magnesium minerals such as carnallite, epsomite and kieserite have been located in the main Permian basin of west Texas. What, then, became of the enormous quantities of magnesium?

The next and final phase of the exploration is the sinking of a number of core wells which will furnish quantitative data concerning the thickness and purity of the polyhalite strata. The first core test in each area should be drilled adjacent to the cable tool test which indicates the thickest and richest polyhalite stratum. The cable tool test is merely a guide; the complete physical nature of the bed can be determined only by a core test.

The development of a polyhalite industry is seriously handicapped by the lack of a good supply of the crude ore. Polyhalite is not being mined anywhere in the world at the present time, hence none is available for either agricultural or refining experimentation. Conversely, the lack of such material for experimental purposes and of proof of commercial possibilities is the real detriment to the development of a Texas potash industry. The preliminary work done by Schoch, Storch, Fraps, Reynolds, and others has pointed out the possibiilties of refining polyhalite and of using the material *per se* as a fertilizer. The next step is development of a source of the crude ore and the utilization of it for large scale experimentation.

POTASSIUM SULFATE FROM POLYHALITE

E. P. SCHOCH

SUMMARY[1]

In the final method, lime slurry and polyhalite are heated separately to a desired temperature (*e.g.*, 220° C.) and are mixed in the presence of such an amount of water as to produce potassium sulfate solutions with concentrations as high as possible, yet far enough below the equilibrium concentration to obtain immediately a solid practically free from pentasalt. Thus the time of treatment is reduced to 15 minutes, and solutions can be obtained containing about 13.7 grams of potassium sulfate per 100 grams of water (about one-tenth of this being in the form of hydroxide), and the magnesium can be easily converted entirely to light carbonate of magnesia. Finally, as will be shown later, the large amount of anhydrite obtained can be readily converted to plaster. Thus polyhalite appears to be economically usable.

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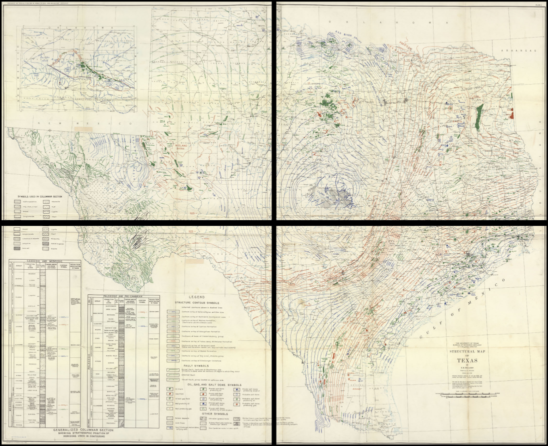
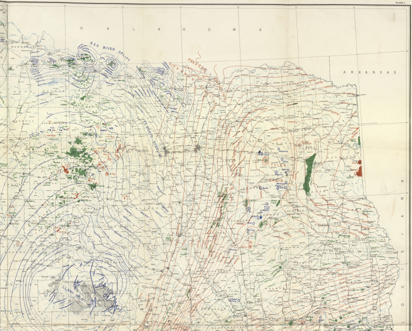
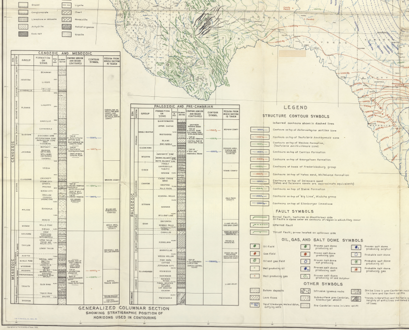
[1]From Industrial and Engineering Chemistry, vol. 27, p. 467, April, 1935. The method of which summary is given is the fourth and, as stated by the author, the most satisfactory method devised for this purpose.

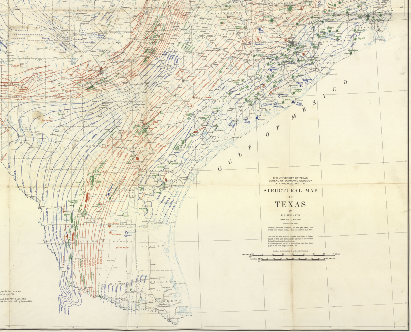
STRUCTURAL MAP OF TRANS-PECOS TEXAS, SCALE 1:1,000,000.


OKLAHOMA
NEW MEXICO
ARKANSAS
RED RIVER UPLIFT
MIDLAND BASIN
GULF OF MEXICO
SYMBOLS USED IN COLUMNAR SECTION
CENOZOIC AND MESOZOIC
CENOZOIC
MESOZOIC
PALEOZOIC AND PRE-CAMBRIAN
PALEOZOIC
GENERALIZED COLUMNAR SECTION
SHOWING STRATIGRAPHIC POSITION OF
HORIZONS USED IN CONTOURING
LEGEND
STRUCTURE CONTOUR SYMBOLS
FAULT SYMBOLS
OIL, GAS, AND SALT DOME SYMBOLS
OTHER SYMBOLS
THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY
STRUCTURAL MAP
OF
TEXAS


O K L A H O M A
N E W M E X I C O
MIDLAND BASIN
SYMBOLS USED IN COLUMNAR SECTION
Sand or sandstone
Clay, shale, or marl
Gravel
Conglomerate
Novaculite
Tuff
Lignite
Chert


O K L A H O M A
ARKANSAS
RED RIVER UPLIFT
FT. WORTH SYNCLINE
TYLER BASIN
LLANO UPLIFT
L O U I S I A N A


Gravel
Conglomerate
Limestone or dolomite
Anhydrite
Lignite
Chert
Novaculite
Schist or gneiss
Granite
CENOZOIC AND MESOZOIC
PALEOZOIC AND PRE-CAMBRIAN
CENOZOIC
MESOZOIC
PALEOZOIC
GENERALIZED COLUMNAR SECTION
SHOWING STRATIGRAPHIC POSITION OF
HORIZONS USED IN CONTOURING
LEGEND
STRUCTURE CONTOUR SYMBOLS
Inferred contours shown in dashed lines
Contours on top of Heterostegina antillea zone
Contours on top of Textularia hockleyensis zone
Contours on top of Weches formation, (Textularia smithvillensis zone)
Contours on top of Carrizo formation
Contours on top of Georgetown formation
Contours at base of Fredericksburg group
Contours on top of Yates sand, Whitehorse formation
Contours on top of Delaware sand (Yates and Delaware sands are approximate equivalents)
Contours on top of Blaine formation
Contours on top of "Big Lime", Wichita group
Contours on top of Ellenburger limestone
FAULT SYMBOLS
Normal fault; hachures on downthrown side
All faults in same color as contours of region in which they occur
Inferred fault
Thrust fault; arrow located on upthrown side
OIL, GAS, AND SALT DOME SYMBOLS
Oil field
Gas field
Oil and gas field
Well producing oil
Well producing gas
Proven salt dome producing oil
Proven salt dome producing gas
Proven salt dome not producing
Proven salt dome producing salt
Proven salt dome producing oil and sulphur
Proven salt dome producing sulphur
Probable salt dome
Probable salt dome producing oil
Probable salt dome producing gas
OTHER SYMBOLS
Bolson deposits
Lava flows
Top of Ellenburger, sea level datum, outlying wells
Intrusive igneous rocks
Subsurface pre-Cambrian, Ellenburger absent
Pre-Cambrian rocks in Llano uplift
Strike lines in pre-Cambrian rocks in Llano and Van Horn uplifts
Trends in Marathon and Solitario uplifts. Heights of anticlines indicated by lengths of lines
MAVERICK


GULF OF MEXICO
THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY
E. H. SELLARDS, DIRECTOR
STRUCTURAL MAP
OF
TEXAS
BY
E. H. SELLARDS
Drawn by C. E. McCarter
Showing structural contours, oil and gas fields, salt domes, and major faults. Contour interval 500 feet.
The base for this map is adapted from map of Texas issued by the Soil Conservation Service of the United States Department of Agriculture.
Acknowledgement for aid in assembling data has been given in the text, pages 10 and 136.
MILES
KILOMETERS
Cambrian rocks
uplifts
and Solitario uplifts
indicated by breadth

INDEX

ADDENDA

Page 72. The South Houston oil field is now a proven salt dome and is so shown on the map, Plate I. It should, therefore, be transferred from Group II to Group I in the list of salt domes. This part of the text had been printed before the salt had been drilled into on this dome.

Page 664. The elevation given for wells on this and succeeding pages is to be regarded as approximate only. This is true also of the depth to salt as given in these wells.