Publications Committee

THE UNIVERSITY OF TEXAS MINERAL SURVEY.

24

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Min Surv S.

REPORT OF A

RECONNAISSANCE IN TRANS-PECOS TEXAS

NORTH OF THE

TEXAS AND PACIFIC RAILWAY.

BY

GEORGE BURR RICHARDSON.

BULLETIN OF THE UNIVERSITY OF TEXAS

NO. 23.

Entered in the Postoffice at Austin, Texas, as mail matter of the second class.

AUSTIN:
VON BOECKMANN-JONES COMPANY, STATE PRINTERS
1904

DEAR SIR: I take pleasure in sending to you a copy of Bulletin No. 9 of The University of Texas Mineral Survey, entitled "Report of a Reconnaissance of Trans-Pecos Texas, North of the Texas & Pacific Railway," by George Burr Richardson.

This Bulletin is the ninth in the series which was begun in July, 1901. The other Bulletins are as follows:

1. Texas Petroleum, July, 1901.
2. Sulphur, Oil and Quicksilver in Trans-Pecos Texas, February, 1902.
3. Coal, Lignite and Asphalt Rocks, May, 1902.
4. The Terlingua Quicksilver Deposits, Brewster County, October, 1902.
5. The Minerals and Mineral Localities of Texas, January, 1903.
6. The Mining Laws of Texas and Tables of Magnetic Declination, July, 1903.
7. Report of Progress for 1903, and Topographic Map of Terlingua Quadrangle in Brewster and Presidio Counties, January, 1904.
8. The Geology of the Shafter Silver Mine District, Presidio County, June, 1904.

These Bulletins are for gratuitous distribution among the citizens of the State and to others upon application.

The editions of Bulletins Nos. 1 to 5, inclusive, have been exhausted.

Very truly,

WM. B. PHILLIPS,

Director.

Austin, Texas, November, 1904.

389-904-6m.

REPORT

OF A

RECONNAISSANCE IN TRANS-PECOS TEXAS

NORTH OF THE

TEXAS AND PACIFIC RAILWAY.

BY

GEORGE BURR RICHARDSON

AUSTIN, TEXAS:
VON BOECKMANN-JONES COMPANY, STATE PRINTERS.
1904.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C., June 10, 1904.

SIR: In accordance with plans of co-operation, I transmit herewith a report entitled "A Reconnaissance in Trans-Pecos Texas north of the Texas and Pacific Railway," by Mr. G. B. Richardson, for publication as a Bulletin of the University of Texas Mineral Survey.

Respectfully,
H. C. RIZER,
Acting Director.

DR. WM. B. PHILLIPS,
Director, University of Texas Mineral Survey, Austin, Texas.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY, WESTERN SECTION OF HYDROLOGY,
WASHINGTON, D. C., June 2, 1904.

SIR: I have the honor to forward a report of a reconnaissance in Trans-Pecos Texas north of the Texas and Pacific Railway, by Mr. G. B. Richardson. It is intended for transmission to Dr. William B. Phillips, Director of the University of Texas Mineral Survey, for publication by that Bureau.

The field and office work on this report has been done by Mr. Richardson, detailed from the Section of Hydrology, but the field expenses and the cost of preparation of illustrations have been defrayed by the State of Texas. The report is an important contribution to our knowledge of the geology and underground water resources of a portion of the Trans-Pecos Texas region, which will be of value and interest to many persons.

Very respectfully,
N. H. DARTON,
Geologist in Charge.

The Director, U. S. Geological Survey,
Through Mr. F. H. Newell, Chief Engineer.

LETTER OF TRANSMITTAL.

Hon. Wm. L. Prather, President, The University of Texas.

DEAR SIR: I beg to transmit herewith a "Report of a Reconnaissance in Trans-Pecos Texas, North of the Texas & Pacific Railway," by Mr. George Burr Richardson.

In the prosecution of a plan of co-operation between this Survey and the United States Geological Survey, Mr. Richardson was detailed from the government service in the spring of 1903 and assigned to this work. He spent six months in the field, and the results of his observations are embodied in this report. In addition to the data gathered in person, Mr. Richardson has availed himself of the results of the work of other geologists there, and I think that his report is a valuable contribution to our knowledge of that region.

Very respectfully,

WM. B. PHILLIPS,

Austin, Texas, November, 1904. Director.

ANNOUNCEMENT.

The University of Texas Mineral Survey has a well-equipped chemical and assay laboratory and is prepared to undertake all kinds of analyses and assays.

Prices will be furnished on application.

Address all communications to

DR. WM. B. PHILLIPS, Director,
Austin, Texas.

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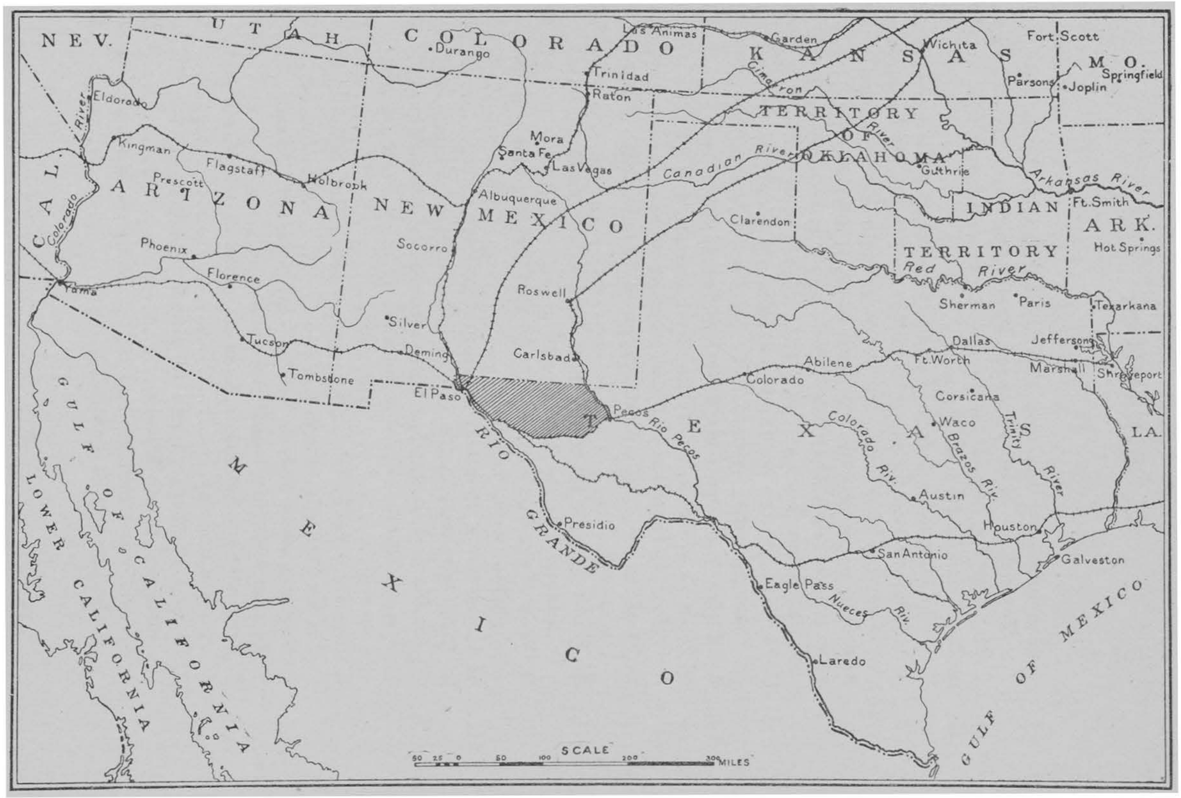


Plate II. Map showing general location of the reconnaissance.

INTRODUCTION.

The reconnaissance reported upon in the following pages was undertaken primarily to determine the conditions of occurrence of underground water. The area studied is situated in Western Texas between the Pecos River and the Rio Grande, and extends from the Texas and Pacific Railway northward to the New Mexico boundary (Plate 2). It includes about 9000 square miles and is somewhat larger than the State of Massachusetts. Six months, from June to December, 1903, were spent in the field.

Dr. Wm. B. Phillips, Director of the University of Texas Mineral Survey, offered every facility at his command for the furtherance of the work. Messrs. C. D. Walcott, T. W. Stanton, G. H. Girty, and E. O. Ulrich kindly examined the paleontologic collections, and Mr. E. H. Elder, a student in the University of Texas, assisted for three months in the field.

G. B. RICHARDSON.

REPORT OF A RECONNAISSANCE IN TRANS-PECOS TEXAS

NORTH OF THE

TEXAS AND PACIFIC RAILWAY.

BY

GEORGE BURR RICHARDSON.

PREVIOUS WORK.

The first detailed geologic knowledge of the area under consideration was obtained as a result of the Mexican Boundary Survey and the surveys for a Pacific Railway.

C. C. Parry and Arthur Schott, connected with the Mexican Boundary Survey, which was under the direction of Major W. H. Emory,[1] made observations in the Rio Grande Valley in 1853 and 1854, and James Hall and T. A. Conrad reported on the fossils collected. This work made known the widespread occurrence of rocks of the Cretaceous and the Carboniferous systems and called attention to the probable presence of the Silurian in the Franklin Mountains.

Captain John Pope, who had charge of the military survey for a Pacific Railway adjacent to the 32d Parallel, in 1853 traveled eastward from El Paso, via the Hueco, Cornudas and Guadalupe mountains, to the mouth of Delaware Creek. No geologist was attached to this expedition, but fossils were collected. These were referred to Jules Marcou, who wrote a preliminary report,[2] and were finally worked up by W. P. Blake.[3]

Between 1855 and 1857, Captain Pope made an artesian well experiment in the Pecos Valley east of the mouth of Delaware Creek. He went over the same route he had traversed before, and was accompanied by G. G. Shumard. The artesian experiment proved a failure, and no formal report was published by the War Department,[4] although notice

[1]Report on the United States and Mexican Boundary Survey, by Wm. H. Emory, Vol. I, Part 2, Washington, 1857.

[2]Report of the Secretary of War, 1855, House Doc. 129, Vol. IV, Chap. 13.

[3]Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean. Vol. II, Washington, 1855.

[4]Report of Captain Humphries to the Secretary of War, Ex. Doc., 1st Sess. 34th Cong., Vol. I, Part 2, 1855-56.

of the work appeared in several papers in the Transactions of the St. Louis Academy of Science.[5] Shumard's[6] observations were finally published in 1886 by the State of Texas. Shumard noted in detail the geology along the route of travel, and his papers long served as the chief source of information concerning the geology of that region. A notable result of this work was the announcement, by B. F. Shumard, of the presence of the Permian in the Guadalupe Mountains.

During the thirty years following these explorations little attention was given to the geology of this region except in two short but important papers. In 1869, J. P. Kimball[7] published an article on the geology of Western Texas, in which he discussed the paleontologic relations. In 1874, W. P. Jenney[8] made a section of the Franklin Mountains and first called attention to the occurrence of the Cambrian in that region.

With the establishment of the Geological Survey of Texas, in 1888, systematic work was begun in the trans-Pecos country. The results were reviewed by E. T. Dumble in the annual reports of that Survey, from 1889 to 1893, and detailed observations over a large area were made by W. H. von Streeruwitz.[9] Mr. von Streeruwitz did pioneer work under considerable difficulty, but a fund of information is contained in his reports. The Survey was discontinued, in 1892, before much correlation was attempted and before a geologic map was prepared.

The Geological Survey of Texas also issued the following reports on the region:

A preliminary report on the soils and waters of the Upper Rio Grande and Pecos Valleys in Texas, by H. H. Harrington; Bulletin No. 2, Geological Survey of Texas, 1890.

A report on the Cretaceous deposits of part of El Paso county, by J. A. Taff; Second Annual Report of the Geological Survey of Texas, pp. 714-738, 1891.

Notes on the geology of the country west of the Plains, by W. F. Cummins; Third Annual Report of the Geological Survey of Texas, pp. 201-223, 1892.

A posthumous publication of G. G. Shumard, entitled "Artesian Water on the Llano Estacado"; Bulletin No. 1, Geological Survey of Texas, 1892.

A reconnaissance of the Guadalupe Mountains, by R. S. Tarr; Bulletin No. 3, Geological Survey of Texas, 1892.

[5] Transactions St. Louis Academy of Science, Vols. I and II, 1860 and 1868.

[6] A partial report on the geology of Western Texas, by G. G. Shumard, Austin, 1886.

[7] American Journal of Science, Second series, Vol. 48, 1869, p. 379.

[8] American Journal of Science, Third series, Vol. 7, 1874, p. 25.

[9] W. H. von Streeruwitz, Geology of Trans-Pecos Texas, Preliminary Statement; First Annual Report of the Geological Survey of Texas, pp. 217-235, 1890.
Report on the geology and mineral resources of Trans-Pecos Texas; Second Annual Report of the Geological Survey of Texas, pp. 665-713, 1891.
Trans-Pecos Texas; Third Annual Report of the Geological Survey of Texas, pp. 381-389, 1892.
Trans-Pecos Texas; Fourth Annual Report of the Geological Survey of Texas, pp. 139-175, 1893.

A report on the rocks of Trans-Pecos Texas, by A. Osann; Fourth Annual Report of the Geological Survey of Texas, pp. 123-138, 1893.

A number of other contributions to the geology of this country have been published, the most important of which, chronologically arranged, are as follows:

Mining districts in El Paso county, by W. F. Cummins, Geological and Scientific Bulletin, Vol. I, No. 2, Houston, 1888.

Mines worked in Western Texas, by W. H. von Streeruwitz, Geological and Scientific Bulletin, Vol. I, No. 12, Houston, 1889.

The existence of artesian waters west of the 97th Meridian, etc.; by E. T. Dumble, 51st Congress, 1st Session, Senate Ex. Doc. No. 222, 1890, pp. 99-102.

Report on the Arid Region (of Texas), by F. E. Roessler, 51st Congress, 1st Session, Senate Ex. Doc. No. 222, pp. 292-319, 1890.

Preliminary notes on the Topography and Geology of Northern Mexico and Southwest Texas and New Mexico; by R. T. Hill, American Geologist, Vol. VIII, pp. 133-141, 1891.

On the occurrence of artesian and other underground waters in Texas, Eastern New Mexico and Indian Territory; by R. T. Hill, Senate Ex. Doc. 41, Part 3, 52d Congress, 1st Session, 1893.

Sources of the Texas drift; by E. T. Dumble, Transactions Texas Academy of Science, Vol. I, No. 1, p. 11, 1892.

Notes on the Texas-New Mexico region; by R. T. Hill, Bulletin, Geological Society of America, Vol. III, pp. 85-100, 1892.

On the precious and other valuable metals of Texas; by W. H. von Streeruwitz, Transactions Texas Academy of Science, Vol. I, No. 1, p. 19, 1892.

The Kent Section; by E. T. Dumble and W. F. Cummins, American Geologist, Vol. XII, pp. 309-314, 1893.

The Cretaceous formations of Mexico and their relations to North American geographic development; by R. T. Hill, American Journal of Science, 3d Series, Vol. XLV, pp. 307-324, 1893.

The Cretaceous of Western Texas and Coahuila, Mexico; by E. T. Dumble, Bulletin Geological Society of America, Vol. VI, pp. 375-388, 1895.

Section of the Cretaceous at El Paso, Texas; by T. W. Stanton and T. Wayland Vaughan, American Journal of Science, 4th Series, Vol. I, pp. 21-26, 1896.

Notes on Native Sulphur in Texas; by E. A. Smith, Science, New Series, Vol. III, pp. 657-659, 1896.

Discovery of marine Jurassic rocks in Southwestern Texas; by F. W. Cragin, Journal of Geology, Vol. V, pp. 813-820, 1897.

Physical Geography of the Texas Region; by Robt. T. Hill, United States Geological Survey, Topographic Atlas of the United States, Folio No. 3, 1900.

El Paso Tin Deposits; W. H. Weed, Bulletin United States Geological Survey, No. 178, 1901.

The red sandstone of the Diablo Mountains, Texas; by E. T. Dumble, Transactions Texas Academy of Science, Vol. IV, Part 2, p. 1, 1902.

The Upper Permian in Western Texas; by G. H. Girty, American Journal of Science, 4th Series, Vol. 14, pp. 363-368, 1902.

With the creation of the University of Texas Mineral Survey in 1901, another period of active geologic work in Trans-Pecos Texas under State auspices was begun. The first report of this Survey dealing with the area under consideration is:

Sulphur, Oil and Quicksilver in Trans-Pecos Texas; by W. B. Phillips, E. M. Skeats, and B. F. Hill. Bulletin No. 2, University of Texas Mineral Survey, 1902.*

TOPOGRAPHY.

GENERAL STATEMENT.

The Trans-Pecos region is different from all other parts of Texas. The greater portion of the State is occupied by plains which rise gradually westward, but beyond the Pecos the plains are succeeded by mountains. This transition marks the boundary between the Great Plains and Cordilleran provinces. The area under consideration lies in both these provinces, but mostly within the Cordilleras, the eastern limit of which corresponds roughly with the western boundary of Reeves county.

The Cordilleran province in the Southwestern United States and adjacent parts of Mexico has been little studied. The Trans-Pecos region extends southward from the Rocky Mountains, which terminate in Northern New Mexico, and is quite different from them. This region has some of the characteristics of both the Basin Ranges and of the Mexican Plateau,[10] but further work must be done before it can be separated into physiographic subdivisions.

The area under consideration is a mountainous country lying between two broad relatively low valleys. On the east the Pecos River flows southeasterly parallel with the trend of the Cordilleras, the western limit of its valley marking the division between the plains and the mountains. On the west the Rio Grande flows southeasterly parallel with the Pecos, through the Cordilleran province. This northwest-southeast trend is the dominant topographic feature of the region.

Trans-Pecos Texas north of the Texas and Pacific Railway is separated into the following natural divisions, beginning on the west: The Mesilla Basin, a part of the Rio Grande Valley; the Franklin Mountains; the Hueco Basin; the Diablo Plateau, flanked on the west by the Hueco and Finlay mountains and the Sierra Blanca, and on the east by the Sierra Tinaja Pinta and the Cornudas, Black, and Diablo mountains; the Salt Basin; the Guadalupe-Delaware mountains; the Rustler

*The Terlingua Quicksilver Deposits, Brewster County, Texas. Bulletin No. 4, University of Texas Mineral Survey, 1902, and The Geology of the Shafter Silver Mine District, Presidio County, Texas, by J. A. Udden. Bulletin No. 8, University of Texas Mineral Survey, 1904, deal with other parts of trans-Pecos Texas.

[10] Hill, R. T. The Geographic and Geologic Features of Mexico. Transaction American Institute Mining Engineers, Vol. XXXII, 1902, p. 163.

Hills and the Toyah Basin, which forms a part of the Pecos Valley. As a whole, the region is a series of northwest-southeast trending areas of high land separated by parallel belts of lowland. These lowland belts are characteristic of the region. Hill[11] calls them both basins and bolson plains, which he describes as "apparently level valleys, usually slightly depressed toward the center and inclosed by mountains. . . . They are largely structural in origin and are generally floored with loose unconsolidated sediments derived from the higher peripheral regions. . . . Some of these sediments may be of lacustral origin."

MESILLA BASIN.

The Mesilla Basin, named by Hill[12] from Mesilla Park in Southern New Mexico, is one of a series of long and relatively narrow basins through which the Rio Grande flows for the greater part of its Cordilleran course. Only a small part of this basin is in Texas. From Anthony on the State line southward the basin narrows and finally ends near the site of the proposed international dam about 4 miles above El Paso, where rocks of Cretaceous age outcrop close to the river. The flood plain on the east side of the Rio Grande is here about 2 miles wide, and its upper margin, at an elevation of about 3800 feet, extends approximately parallel with the Santa Fe Railway. East of the railway the surface rises gradually for 6 miles to an elevation of about 4500 feet at the western base of the Franklin Montains. This part of the Mesilla Basin is much dissected by mountain arroyas. The Rio Grande leaves the Mesilla Basin and enters the Hueco Basin at the constricted part of the valley forming the pass from which the city of El Paso is named.

HUECO BASIN.

The Hueco Basin* is about 200 miles long, 75 miles of which are within the area covered by this report. Here the basin lies between the Franklin Mountains on the west and the Hueco and Finlay mountains on the east, and extends from El Paso to beyond Fort Hancock. The Rio Grande flows in a wide flood plain, the northern border of which is followed approximately by the Galveston, Harrisburg and San Antonio Railway, and the Texas and Pacific Railway. Northeast of the railway is a steep escarpment about 250 feet high, marking the depth to which the river has cut into the basin deposits beneath the surface of the plain.

From this escarpment northward to the State line the Hueco Basin

[11]Physical Geography of the Texas Region, United States Geological Survey, Folio 3.

[12]The writer wishes to acknowledge his indebtedness to Mr. Hill, not only for the information contained in his publications relating to trans-Pecos Texas, but also for many personal suggestions. It is regretted that Mr. Hill's absence prevented his criticism of this report before it went to press.

*The northern continuation of the Hueco Basin is known as the Tularosa desert.

rises gently, but it is remarkably even and only a little dissected. Where the basin abuts against the mountains a wide fringe of debris extends out on the flat, which itself is capped by fine-textured detritus or by caliche. In the vicinity of El Paso, where the basin is locally known as the Mesa, are several distinct terraces, but they can not be traced far. The bluff which marks the limit of the flood plain extends in a fairly even course and in general is but little dissected. North of Fort Hancock the bluff as such disappears, and the entire basin is minutely dissected into typical bad land topography.

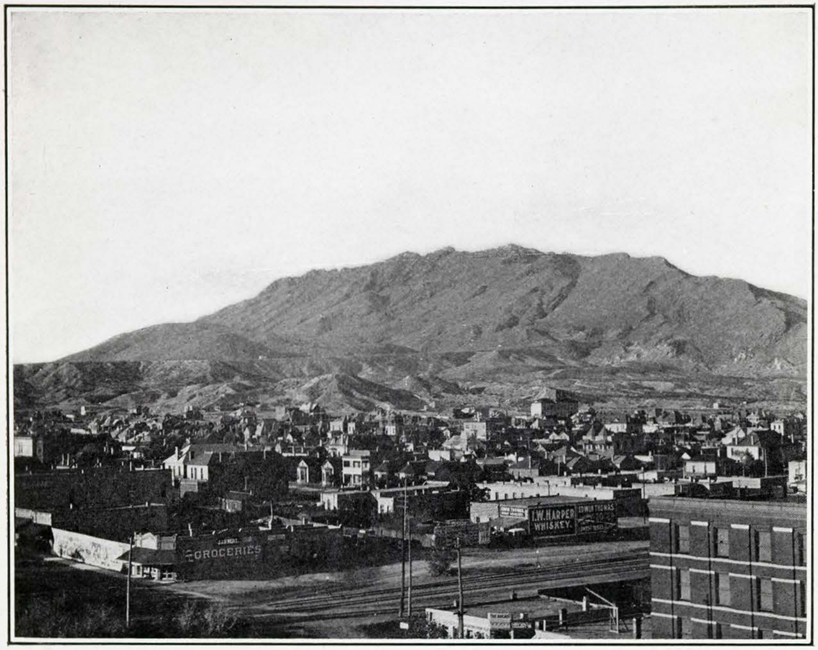
FRANKLIN MOUNTAINS.

Between the Hueco and Mesilla basins are the Franklin Mountains, which extend north of El Paso for a few miles beyond the State line, where they are separated by a low pass from their northern continuation —the Organ Mountains. In Texas the Franklin Mountains have a length of about 15 miles and an average width of only 3 miles. They rise over 3000 feet above the adjacent basins, North Franklin Peak having an elevation of 7140 feet. This narrow range is characterized by good exposures of rocks which dip steeply to the west (Plate III, *A*). The range is considerably dissected, more so on the east than on the west. Near the summit, east-facing ledges in many places effectively prevent the scaling of the range from that direction, but there are several trails across the mountain.

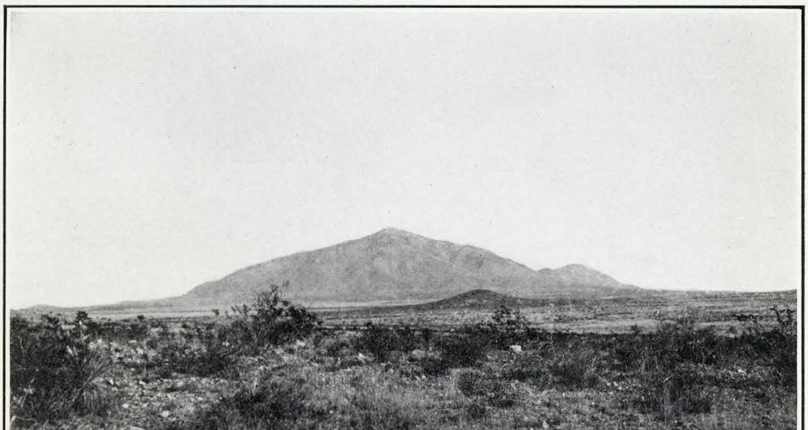
DIABLO PLATEAU.

The Diablo Plateau is a distinct flattish-topped upland, having an area approximately 1200 square miles in the region under consideration. It is underlain by flat-lying and gently inclined limestones, and its escarpments are so dissected that they are given separate names. On the west are the Hueco and Finlay mountains, and on the southeast the Diablo Mountains. The northeastern border of the plateau in Texas is marked by the Cornudas Mountains and the Sierra Tinaja Pinta, which consist largely of igneous rocks.

The surface of this plateau is not flat over wide areas. It slopes gently eastward in the Hueco Mountains and westward in the Diablo Mountains. North of the Finlay Mountains horizontal Cretaceous limestones rise slightly above the surrounding Carboniferous limestone. The drainage is northerly and easterly to the Salt Basin, toward which, between the Sierra Tinaja Pinta and Black mountains, the surface gradually slopes, yet in spite of these variations the plateau nature of the area is distinct and striking.



A. MOUNT FRANKLIN FROM EL PASO.



B. SIERRA BLANCA PEAK FROM SIERRA BLANCA STATION.

HUECO MOUNTAINS.

The dissected northwestern scarp of the Diablo Plateau is known as the Hueco Mountains. Up to the scarp the surface of the plateau inclines gradually eastward as a dip slope. This scarp varies from 5 to 10 miles in width, and its top has an average elevation of about 1000 feet above the Hueco Basin. It is considerably dissected, and drains westward. Near the State line an abrupt scarp about 600 feet high faces the Hueco Basin. Cerro Alto, a conical peak of igneous rock in the northern part of the mountains, rises to a height of 6767 feet—over 1000 feet above the general level of the mountains.

FINLAY MOUNTAINS.

Southeastward from the Hueco Mountains the western limit of the Diablo Plateau is marked by an abrupt escarpment, which has a height of about 500 feet and a length of about 20 miles. At the southern end of the escarpment the rocks are folded into a rude dome, which has been dissected by erosion into a group of hills called the Finlay Mountains.

This dome is somewhat elliptical in outline, and its major axis, following the general northwest-southeast trend, is about 9 miles long. The width of the mountains from northeast to southwest is about 6 miles. In general the drainage is away from the center of the uplift, in all directions, but erosion has acted irregularly, and the high central ridge marking the northeastern limb of the fold stands out in contrast to the southwestern limb that has been much dissected. The outlying hills show good rock exposures which emphasize the dome structure.

SIERRA BLANCA.

Southeast of the Finlay Mountains and separated from them by a few miles of wash-covered plain are the Sierra Blanca—a group of four conical peaks composed mainly of igneous rocks, the highest having an elevation of almost 7000 feet (Plate III, *b*). These peaks rise abruptly above a plain that adjoins the Hueco Basin on the west and is connected with the Salt Basin on the east by a northwest-southeast trending lowland about 30 miles long and averaging 5 miles in width, known as Eagle Flat. This lowland extends from Sierra Blanca and Eagle Flat stations southeastward along the Galveston, Harrisburg and San Antonio Railroad, and merges into the Salt Basin at the north end of the Van Horn Mountains about 7 miles south of the town of Van Horn.

DIABLO MOUNTAINS.

North of Sierra Blanca the southern limit af the Diablo Plateau is marked by a low escarpment, which to the eastward reaches a considerable elevation and becomes the southern end of the Diablo Mountains.

The Diablo Mountains form the southeastern extremity of the Diablo Plateau and give the name to the latter. These mountains extend about 25 miles from north to south and are flanked on the south, east and northeast by an abrupt escarpment, which is steepest on the east, where it rises over 2000 feet above the Salt Basin. The mountains are capped by a massive limestone that dips westward at a low angle with which the general slope of the surface corresponds. But the higher, eastern points of the mountains are considerably dissected by erosion. Very little of the drainage passes directly eastward into the Salt Basin, the principal outlets being to the south, west and northeast.

BLACK MOUNTAIN, SIERRA TINAJA PINTA, AND CORNUDAS MOUNTAINS.

Northwestward from the Diablo Mountains the surface of the plateau slopes gradually eastward to the Salt Basin, the drainage passing between the Diablo and Cornudas mountains. The northeastern limit of the Diablo Plateau in the State of Texas is marked by isolated mountains known as Black Mountain, Sierra Tinaja Pinta and Cornudas mountains. These are mainly composed of igneous rocks, which have been thrust up through surrounding sediments.

The Cornudas are the most extensive of these. They lie near the State boundary, and their greatest extent is in New Mexico. They constitute a striking group of odd-shaped forms that rise abruptly above the surrounding plain. The highest of the Cornudas in Texas is San Antonio Peak, which is a cone-shaped mountain having an elevation of 7020 feet above sea and 2000 feet above the surrounding country. Southeast of San Antonio is Washburn Mountain, flat-topped and considerably lower, while northeast of San Antonio and just north of the State boundary is another high, conical mountain called Wind Peak.

South of the Diablo Mountains between Eagle Flat and Allamoore are low-lying hills composed largely of pre-Cambrian rocks. Farther east the hills become higher, and north of Allamoore and Van Horn these old rocks are capped by Ordovician and Carboniferous limestone.

SALT BASIN.

The Salt Basin is one of the prominent debris-filled inter-montane valleys of the Trans-Pecos country. It has the characteristic northwest-southeast trend and is over 150 miles long. The area under consideration includes 70 miles of the linear extent of the Salt Basin, which here ranges from 8 to 20 miles in width, averaging about 15 miles.

The Salt Basin is a typical closed basin with no drainage outlet. The center is about 25 miles north of Van Horn at the base of the Diablo Mountains, where the elevation is below 3600 feet. The rise is very gradual both to the north and to the south. Northward from the center of the basin to the State line the slope of the surface is only about 2 feet in a mile. This inclination is unappreciable to the eye, and the basin appears to be flat in its longer extent and to rise only to the adjacent highlands on the northeast and southwest. The surface of the basin is not a level plain, but is characterized by numerous hillocks and local depressions. The former often are composed of wind-blown material, and the latter are locally called lakes. Only one prominent body of water is found. This is the shallow lake which is near the center of the basin and is about 3½ miles long and ½ mile wide. The water is extremely salty. Most of the local depressions are marsh areas that contain water only for a short time during the rainy season. Many of these temporary lakes are floored with gypsum containing traces of other salts.

In the center of the basin the surface is covered by gypsum, which is locally abundant, silt and fine-textured materials, but toward the periphery it is covered with coarse detritus derived from the immediate vicinity.

GUADALUPE-DELAWARE MOUNTAINS.

The Guadalupe-Delaware Mountains constitute an eastward-sloping monocline and present a steep scarp to the Salt Basin. This escarpment is especially prominent in the northern part of the area, where it rises almost 5000 feet above the adjacent plain. Southward the difference in elevation decreases to about 1000 feet.

The Guadalupe Mountains extend into Texas from New Mexico, crossing the State line about 45 miles west of the Pecos River. Here the mountains are 10 miles wide, but they converge in a wedge-shaped form and abruptly terminate about 10 miles south in a precipitous cliff called Guadalupe Point. El Capitan Peak, having an elevation of approximately 8500 feet,* is ¼ of a mile north of Guadalupe Point, and is thought to be the highest point in Texas.

These mountains are capped by massive limestone approximately 2000 feet thick, which overlies softer sandstone. Erosion has dissected the mountains and has cut far below the base of the limestone, which stands out in perpendicular precipices. The chief drainage is eastward, where the headwaters of Black River and Delaware Creek have their sources in canyons that extend into the midst of the mountains. The western face of the Guadalupe Mountains is but little dissected, and no streams have cut across the escarpment. Along the western base are low foothills, which southwest of Guadalupe Point rise to an elevation of 5000 feet.

The Delaware Mountains are the southern extension of the Guadalupes. They extend northwest-southeast uninterruptedly for about 40 miles, beyond which they are considerably dissected and form an irregular, unnamed highland mass which reaches almost to the Texas and Pacific Railway.

The Delaware Mountains constitute a typical cuesta. They have a southwestward-facing scarp approximately 2000 feet high, from the crest of which the surface slopes gradually northeastward conforming approximately with the dip of the underlying rocks. Along the western face of the escarpment is a belt of much dissected foothills, but no

*Barometrical determination.

drainageway cuts across the escarpment in the Delaware Mountains proper. At the southern extremity of the mountains the escarpment becomes indistinct, and a longitudinal valley extends parallel with the axis of a low anticlinal fold.

The streams that drain the Delaware Mountains are mainly consequent and flow down the slope of the monocline. Delaware Creek and the valleys at the heads of Salt and Cottonwood draws are the chief waterways, although none of them excepting Delaware Creek below Delaware Springs are perennial streams. Some lateral streams are developed which flow approximately parallel to the strike of the rocks, Wild Horse Draw being a typical example. Near the crest of the mountains the valleys are steep and narrow, but eastward they broaden out.

GYPSUM PLAIN.

At the eastern base of the Guadalupe-Delaware Mountains there is a gently undulating east-sloping plain that is underlain by gypsum. Within Texas this area is approximately 50 miles in length and averages 15 miles in width, though at the State boundary it is 25 miles wide. The general flatness is relieved by occasional isolated rounded hills that are capped by limestone. The gypsum plain is traversed by Delaware Creek near the State line and farther south by Horseshoe and Cottonwood draws. These waterways occupy broad valleys, in which narrow gorges locally have been entrenched. Delaware Creek, for instance, in its upper course across the Gypsum Plain flows in a narrow channel in the midst of a remarkably flat plain. The gorge is 20 to 30 feet deep and about 300 feet wide at the top. At the bottom of the gorge the creek flows in a narrow flood plain about 30 feet wide. In its lower stretches Delaware Creek widens out, and its canyon-like course gives way to an open valley.

RUSTLER HILLS.

Eastward a narrow range of low hills intervenes between the gypsum plain and the Pecos Valley. These are the Rustler Hills, which extend southwestward from the mouth of Delaware Creek a distance of about 40 miles in a belt averaging 5 miles in width. The Rustler Hills rise 3600 or 3700 feet above sea level and 150 to 250 feet above the adjacent plains. They are capped by limestone, and when viewed from an elevation show an even-topped sky-line. Erosion has dissected these hills somewhat, and Horseshoe and Cottonwood draws flow through them in relatively narrow valleys.

South of the gypsum belt a group of Permian limestone hills that may be considered the southern extension of the Delaware Mountains extends almost to the railroad. Adjacent to the Salt Basin these hills are irregular in outline, but southeastward toward Kent a narrow flat-topped ridge extends for about 20 miles. This ridge rises 400 to 800 feet above the adjacent lowlands.

In the vicinity of Kent and San Martine, at the western end of the Toyah Basin, are a number of detached rounded and irregularly-shaped hills that rise from 100 to 200 feet above the surrounding level. These hills are composed of low-lying Cretaceous rocks, which are the erosion remnants of a former connected mass.

TOYAH BASIN.

The Toyah Basin as defined by Hill[13] is that part of the Pecos Valley lying between the vicinity of the Texas-New Mexico boundary and the escarpment of the Stockton and Edwards plateaus, 50 to 70 miles south of the Texas and Pacific Railway, the east and west limits of the basin being respectively the scarp of the Staked Plains and the mountains to the west. This large area is underlain to a great but unknown depth by unconsolidated materials which may be in part lake deposits.

The portion of the Toyah Basin within the area described is a broad plain that rises gradually westward. The elevation is 2500 feet at Pecos and about 3600 feet at the western border near San Martine. Though in general flat, the basin can be characterized as consisting of broad, gently-undulating valleys separated by intervening low divides. At the western margin a number of "draws" emerge from the hills, but few waterways maintain their channels completely across the basin. Cottonwood Draw is a conspicuous example. This is a comparatively large drainage-way that heads in the Delaware Mountains, but midway across the Toyah Basin it becomes lost in the flat, and being unable to extend its channel to the Pecos River, spreads out aimlessly north of Hermosa. The Pecos River meanders in a broad flood plain into which it has cut a shallow channel. The flood plain slopes gradually away from the river, and locally the border between the flood plain and the Toyah Basin deposits is marked by a low gravel bluff.

STRATIGRAPHY.

GENERAL STATEMENT.

The prevailing rocks of trans-Pecos Texas north of the Texas and Pacific Railway are sedimentary and range in age from pre-Cambrian to Quaternary, almost all of the systems being represented. Pre-Cambrian rocks outcrop in the Franklin Mountains and south of the Diablo Mountains. Cambrian and Ordovician sediments are present in the Franklin Mountains, in the southern Hueco Mountains, and northwest of Van Horn, and the Silurian is represented by small areas of limestone in the Franklin Mountains. There are no rocks of Devonian or Missis-

[13] Physical Geography of the Texas Region, United States Geological Survey, Folio 3.

sippian age in the region under consideration, but there are wide tracts covered by Pennsylvanian limestone. The Permian is represented in the Guadalupe-Delaware Mountains by a considerable thickness of sandstone and limestone containing a unique fauna, and beds of gypsum and other rocks east of the mountain are provisionally assigned to this series. Triassic fossils have not been found, and it is doubtful whether that system is represented, but there is a small interesting occurrence of rocks of Jurassic age in the vicinity of Malone. Cretaceous rocks are abundant in the Finlay Mountains, on the Diablo Plateau, about Sierra Blanca, Kent and elsewhere in the area mapped. The Tertiary apparently is unrepresented by outcrops, but unconsolidated deposits of Quarternary age are found over large areas in the basins.

A variety of igneous rocks including rare alkali-rich types are locally prominent. It has been impossible to study these in time for this report, but analyses are to be made, and some of the more interesting rocks will be described in a subsequent paper.

PRE-CAMBRIAN.

In the region described in this report are two areas of pre-Cambrian rocks. These are south of the Diablo Mountains and along the eastern flank of the Franklin Mountains. In each of these areas the rocks are chiefly sedimentary, but in both igneous rocks also occur. The geology is complex and has not been studied in detail. Future work will make subdivisions, and formation names have not been adopted.

AREA SOUTH OF THE DIABLO MOUNTAINS.

South of the Diablo Mountains between Eagle Flat and Van Horn is a more or less metamorphosed complex, consisting of red sandstone, cherty limestone, breccia and a few igneous intrusions. These rocks have been tilted, folded and faulted. The outcrops for the most part are low-lying and are separated by flat wash-filled areas. A complete section is difficult to measure, and the thickness and relations of these rocks were not determined.

The red sandstone is homogeneous in composition and texture. It is a compact, fine-textured, bright red sandstone, composed of minute quartz grains coated by a red pigment, probably ferric oxide, that gives the uniform color to the rock. More or less calcium carbonate is interstitially disseminated. The sandstone has been much disturbed and is traversed by numerous joint planes, a prominent trend being N. 75° E. Bedding planes, in general, can not be distinguished on account of the homogeneous texture, and it is difficult to measure the thickness. At the southern end of the Diablo Mountains this red sandstone seems to be horizontal and more than 500 feet of it are exposed. At some localities, as at Tumbledown Mountain, 2 miles southeast of the Hazel mine, the red sandstone appears to lie beneath the cherty limestone, but relations have not been definitely determined. Adjacent to the southern Diablo Mountains is a considerable area of fine-textured red sandstone, which is shown on the map, although it does not include all of the red sandstone.

The cherty limestone has a variety of subordinate local phases; but, in general, it is a massive gray semi-crystalline rock, much seamed with crumpled streaks of chert. A partial analysis, by Mr. George Steiger, of a sample collected 3 miles northeast of Eagle Flat, shows a considerable magnesium content. The variations are chiefly in color and in the presence or absence of chert. The color is white to gray, bluish, pinkish, yellowish and mottled. Locally the limestone is free from chert, and northeast of Eagle Flat a fair quality of marble has been reported. This limestone is prominently exposed in the hills north of Eagle Flat and Allamoore, where it strikes approximately east and west and dips steeply to the south. There are local faults and folds, however, and the thickness aggregates at least several hundred feet.

Associated with the limestone and probably overlying it is a coarse breccia, composed of semi-rounded and angular fragments of siliceous limestone and fine-textured red sandstone, which range in size from pieces about a foot in diameter to small pebbles. Some of the fragments are flattened as a result of the stresses to which the rocks have been subjected. Satisfactory measurements of thickness have not been made, but the breccia is at least 100 feet thick.

Locally these rocks have been cut by dikes ranging in thickness from a few feet to about 100 feet. These dikes strike in various directions and generally can not be traced more than a few hundred yards. Both acid and basic types occur, but they have not been observed in juxtaposition. Much-altered diabase and quartz-porphyry have been recognized. Apparently these rocks are also of pre-Cambrian age, for some of them underlie the Van Horn formation.

These old rocks are distinctly unconformably overlain by Paleozoic sediments. In the vicinity of Allamoore and Eagle Flat and in the southern scarp of the Diablo Mountains, the horizontal Hueco formation (Carboniferous) lies upon an eroded surface of the rocks above described, and northeast of Allamoore the almost flat Van Horn formation lies on an eroded surface of sharply-tilted cherty limestone and fine-textured red sandstone. The Van Horn formation is probably of Cambrian age, and therefore these deformed older rocks are classified as pre-Cambrian.

AREA IN THE FRANKLIN MOUNTAINS.

Along the eastern flank of the Franklin Mountains, in an area somewhat less than 10 miles long and about a mile wide, is a group of rocks consisting chiefly of quartzite, slate and interbedded rhyolite, and having a thickness of over 3000 feet. In general these rocks strike north and south and dip westerly at angles of about 20°, corresponding with the prevailing structure of the Franklin Mountains. Details are complex and have not been determined.

In 1896 Mr. C. D. Walcott measured the following section 8 miles north of El Paso.

Section of pre-Cambrian strata on east face of Franklin Mountains, 8 miles north of El Paso.

		Feet.
1i.	Same as (1g), with occasional reddish sandy quartzite	1,265
1h.	Reddish-brown, fine conglomerate passing into reddish-brown and grayish quartzite. Est.	50
1g.	Interbedded rhyolitic-like eruptive, with pebbles (¼ inch to 12 inches in diameter) of quartzite, rhyolitic-like rock and slates (dark). Est.	200
1f.	Sandy shales and slaty beds, similar to (1d)	350
1e.	Light-grey quartzite in evenly-bedded layers, not as massive as below. Strike, north and south; dip, 20° W. Passes gradually into a nearly white quartzite which weathers buff on long exposure, but, as seen in cliffs, gives a light-grey band in the mountain side	395
1d.	Arenaceous slates and shales, with thin layers of grey (steel) quartzite. Strike, north and south; dip, 20° W. Sun cracks abundant in many layers. Dip varies to 25° near top	185
1c.	Darker quartzite than (a), thin-bedded and, with an interbedded greenstone (about 25 feet thick), passing above into a more massive quartzite. The greenstone shows very plainly in the north side of the canyon as a dark interbedded band in the quartzite	220
1b.	Reddish sandy shales in beds 1 to 2 feet thick, with occasional beds of quartzite. Strike, north and south; dip, 13° 15′ W.	275
1a.	Conglomerate, very fine at base, passing up into light quartzite, in layers 6 inches to 2 feet thick. Strike, north and south; dip, 20° W.	360
		3,300

Base, reddish granite?

The granite at the base of the section lies along the east central foot of the mountains. It extends across the northern end of the pre-Cambrian rocks up to the Ordovician limestone, and apparently is post-Ordovician though the age remains to be established. At the top of the section there is an apparent unconformity. Ordovician limestone locally lies upon the older rocks in the central part of the range, while farther south the Ordovician lies upon Cambrian sandstone.

No relationship has been established between the rocks of these two areas. Their outcrops are over 100 miles apart, and there is no lithologic similarity between them. Pre-Cambrian age is all that they are known to have in common. The greater complexity south of the Diablo Mountains, however, is indicative of a more varied history, and it may be that the rocks in this region are older than those in the Franklin Mountains.

CAMBRIAN.

Within the region mapped are three areas whose rocks are classified as Cambrian—in the Franklin and Hueco mountains and northwest of Van Horn. In the two latter localities the classification is based largely on stratigraphic evidence and is only tentative, but in the Franklin Mountains Cambrian fossils have been found in the Bliss sandstone.

BLISS SANDSTONE.

The Bliss sandstone outcrops in the southeastern extremity of the Franklin Mountains in a narrow belt about 3 miles long, and a sandstone which is tentatively correlated with it, but in which no fossils have been found, occurs similarly in the northern part of the Franklin Mountains as mapped.

The formation is a massive, compact, fine-textured gray sandstone about 300 feet thick, but there are minor variations. The color varies from almost white to brown. Toward the top the sandstone is locally cross-bedded and there is a difference in compactness, some of the beds being quite indurated. Mr. Walcott, who visited the locality in 1896, noted that the basal bed is composed of a coarse-grained granitic-like sandstone resembling the igneous rock beneath it.

These rocks contain numerous annelid borings, and a few fossils have been collected, which indicate that the age of the sandstone is Saratogan (upper Cambrian). *Obolus matinalis* (?) and a *Lingulella* were identified by Mr. Walcott, who also found good specimens of *Lingulepis acuminata* and traces of *Hyolithes.*

The Bliss sandstone lies upon a coarse red granite, but the nature of the contact has not been determined. At its top the Bliss sandstone seems to be conformable with the El Paso limestone (Ordovician). This, however, is only apparent, the unconformable nature of the contact being shown by the fact that northward the Bliss sandstone locally disappears, and the El Paso limestone rests directly on the eroded surface of the pre-Cambrian rocks. As indicated on the map the relations of the northern end of this Cambrian outcrop have not been determined.

The Bliss sandstone is named from Fort Bliss, which is situated on the mesa immediately east of the outcrop of the formation.

At the southern extremity of the Hueco Mountains is a narrow belt of sandstone having a length of about 6 miles from east to west. This rock is a rather homogeneous, brown and buff fine-grained sandstone. A maximum thickness of 250 feet is here exposed. The sandstone is somewhat loose-textured and is much less indurated than the Bliss sandstone in the Franklin Mountains. The base of this sandstone in the Hueco Mountains is concealed by unconsolidated sands and gravels of the Hueco Basin, and the top is apparently conformably overlain by massive gray limestone, which contains Ordovician fossils, and which is correlated with the El Paso limestone. No fossils have been found in this sandstone in the Hueco Mountains, but from its relations it is tentatively correlated with the Bliss sandstone.

VAN HORN FORMATION.

In the red valley northwest of Van Horn and in the southern Diablo Mountains are beds of coarse red sandstone and conglomerate, which are named the Van Horn formation.

The most complete section occurs on the east side or the red valley at the base of the mountain north of Van Horn, where about 500 feet of this formation are exposed. The lower half of the section is composed of thick-bedded, coarse red sandstone composed principally of rounded quartz grains, but containing also some feldspar fragments and interbedded bands of conglomerate composed of pebbles of quartz, chert, limestone, fine-textured red sandstone and igneous rock. Above the middle of the section conglomerate does not occur, and the upper 250 feet consists of massive coarse red quartzose sandstone that merges upwards apparently conformably into beds of vari-colored sandstone and white calcareous sandstone, which contain early Ordovician fossils.

At the base of the Van Horn formation is a distinct unconformity. In the vicinity of Carrizo Spring low-lying coarse red sandstone of the Van Horn formation lies on an eroded surface of sharply-tilted fine red sandstone, and cherty limestone previously referred to. The upper contact is variable. In the mountain northwest of Van Horn, as has been noted, the red sandstone of the Van Horn formation merges upward through vari-colored sandstone into whitish sandstone and sandy limestone which contains early Ordovician fossils, but this apparent gradation upward into the Ordovician has not been observed in other sections. At the east end of the mountain, 1 mile west of Van Horn, for instance, tilted coarse red sandstone is overlain by a thin band of horizontal Ordovician limestone less than 100 feet thick, which in turn is overlain by Carboniferous rocks. The contact between the Ordovician limestone and the underlying red sandstone is here concealed, but evidently it is different from the foregoing section. The thin bed of Ordovician limestone was not traced westward, but at the western end of the range of hills between Van Horn and Allamoore the Ordovician is not present and coarse red sandstone is directly overlain by the Hueco formation (Carboniferous). Likewise in the southern Diablo Mountains the Hueco formation immediately overlies the Van Horn formation.

No fossils were found in the Van Horn formation during the reconnaissance of 1903, but, because it occurs stratigraphically below rocks containing early Ordovician fossils and differs in lithologic character from the Ordovician rocks, it was tentatively assigned to the Cambrian. A recent note strengthens this classification. E. T. Dumble states that W. H. von Streeruwitz found borings in rocks of this formation which were identified by C. D. Walcott[14] as *Scolithes linearis*.

At some time previous to the deposition of the Saratogan sediments the pre-Cambrian rocks were uplifted and eroded. In the Van Horn region folding and faulting also occurred, but in the Franklin Mountains the pre-Cambrian rocks apparently were little disturbed until after the deposition of the Paleozoic sediments. The absence of rocks of lower Cambrian age implies that this area in common with the eastern Rocky

[14]Transactions Texas Academy of Science, Vol. IV, Part 2, No. 6, 1902, p. 2.

Mountain region[15] was above sea level during that time. The character of the Van Horn formation implies proximity to shore whence the coarse fragments of older rocks were derived. So, too, the similarity in composition of the basal sediments of the Bliss sandstone and the underlying crystalline rocks implies a near-by origin. The relation of the Van Horn formation to the Bliss sandstone is not known. Probably the Van Horn formation is younger, because apparently it grades conformably into rocks containing lowermost Calciferous fossils.

ORDOVICIAN.

Ordovician rocks occur in the same three areas as the Cambrian, namely, in the Franklin and Hueco mountains and northwest of Van Horn, but they have greater thickness and are more widely distributed. They are chiefly limestones—almost entirely so in the Franklin and Hueco mountains—but in the Van Horn region the base of the section is marked by calcareous sandstones.

EL PASO LIMESTONE.

The main part of the Franklin Mountains is composed of limestone of Ordovician age, which aggregates about 1200 feet in thickness.

The limestone is locally arenaceous at the base, and throughout its extent bands of chert are irregularly distributed. The lowermost limestones also contain a small amount of magnesia, but the greater part is apparently non-magnesian. The formation varies in hardness, and the color ranges from drab and buff with local reddish and bluish streaks to the prevailing gray. On the whole the Ordovician in the Franklin Mountains consists of massive gray limestone, which is named the El Paso Limestone.

This limestone is rich in fossils, of which Mr. S. Ward Loper in 1897 made an extensive collection for the United States Geological Survey. Mr. E. O. Ulrich has hastily examined the collection, and finds that the fossils are from three horizons, which are widely separated in the normal complete section. These horizons are the Calciferous, the Galena-Trenton and the upper Richmond, but the thickness of limestone belonging to the different horizons has not been determined. The absence of the intervening faunas from the collection suggests the presence of unconformities. These, however, have not been recognized.

In the middle Calciferous horizon Mr. Ulrich identified peculiar Cephalopoda related to *Piloceras* and *Cameroceras*. Also *Ophileta* and other gastropods indicative of the Calciferous.

Belonging to the Galena-Trenton horizon are the following:

Receptaculites oweni.

Maclurina manitobensis.

[15]Correlation Papers, Cambrian, United States Geological Survey, Bulletin No. 81, p. 330.

Maclurina acuminata.
Hormotoma major (?).
Ormoceras sp. undet.

The Richmond horizon is represented by the Fernvale fauna, of which there is a rich collection including the following:

Streptelasma rusticum.
Protarea verneuilli (?).
Hemiphragma imperfectum.
Monotryprella quadrata.
Strophomena flexuosa.
Leptaena unicostata.
Dinorthis proavita.
Dinorthis subquadrata.
Platystrophia acutilirata.
Rhynchotrema capax.
Rhynchotrema argenturbica.
Orthis near davidsoni.
Plectorthis whitfieldi.
Parastrophia divergens.

In the southern part of the mountains, as has been mentioned, the El Paso limestone overlies the Bliss sandstone. Farther north the Cambrian locally disappears, and the El Paso limestone in places lies directly and with apparent unconformity on pre-Cambrian rocks. The Ordovician is succeeded by beds of various age. About 2 miles north of El Paso, Silurian limestone outcrops in a low hill at the western base of the mountain, but the contact of the Silurian with the Ordovician is generally concealed and was not determined. Farther north the Pleistocene deposits of the Mesilla Basin rest against the El Paso limestone for several miles, and near the State line Carboniferous limestone appears to lie directly upon the Ordovician though the exact contact was not found.

In the Hueco Mountains about 600 feet of massive gray Ordovician limestone are exposed in the scarp at the southwestern extremity of the mountains. These limestones rest apparently conformably on the sandstone, which tentatively has been correlated with the Bliss sandstone. The exact upper limit of the Ordovician has not been determined, but no Silurian fossils have been found in this region, and it is believed that the Hueco formation lies directly on the Ordovician. Among the Calciferous fossils collected from this locality Mr. Ulrich recognizes several species of *Ophileta*, *Syntrophia* and Cystidean stems. This Ordovician limestone is correlated with the El Paso limestone on lithologic and faunal evidence.

VAN HORN AREA.

The Van Horn Ordovician area is best exposed in the west side of the round mountain north of Van Horn. Here Mr. E. H. Elder measured the following section:

Section on the west side of the mountain 6 miles northwest of Van Horn.

		Feet.
8.	Massive light gray limestone thinner bedded toward the base	200+
7.	Fine textured white sandstone	25
6.	Thin bedded buff limestone	100
5.	Massive fine textured white sandstone	25
4.	Thin bedded white sandstone	30
3.	Thin bedded buff sandstone	20
2.	Vari-colored sandstone	75
1.	Coarse red sandstone	8

From the fossils collected at the top of this section Mr. Ulrich correlates it with the middle Calciferous horizon of the Franklin Mountains. The few fossils found in the underlying calcareous sandstone are characteristic of the base of the Ordovician system and even suggest the presence of the upper Cambrian.

On the northern side of the round mountain north of Van Horn, below the massive limestone, the lower light sandstones include thin beds of sandy limestone in which early Ordovician fossils have been found, but the base of the section is not paleontologically established. As has been noted, the whitish sandstones merge downward apparently conformably through vari-colored sands to the coarse red sandstones of the Van Horn formation. The top of the Ordovician in this locality has not been determined. Pennsylvanian fossils have been found on the summit of the mountain, but the position of the base of the Pennsylvanian remains to be established. Rocks of Silurian age have not been found in the Van Horn region.

SILURIAN.

Little more is known of the Silurian system in the area mapped than that gray limestone of that age outcrops in a few small areas in the Franklin Mountains. The outcrops near the State line and west of Fort Bliss appear to be faulted out of their normal positions and will be referred to below. In the area immediately north of El Paso the Silurian overlies the Ordovician, but the contact is obscure. The fauna, however, suggests an unconformity. Mr. E. O. Ulrich states that the commonest fossils from the Silurian of this area is a species of radially plicated pentameroid shell (*Conchidium*), which with *Amplexus* and *Favosites* indicate that the upper Niagara is here represented.

Whether Silurian rocks extended over a large part of the area under consideration can not be determined. None have been recognized in the Hueco Mountains or in the Van Horn region, where their presence might be expected. This absence, however, does not imply nondeposition of Silurian rocks in these areas, for between Silurian and Pennsylvanian time this region was uplifted from the sea and exposed to subaerial conditions.

There are no rocks of Devonian or Mississippian age in this region, and wherever the lowermost Pennsylvanian sediments are exposed there is evidence of profound unconformity. This is most apparent in the Van Horn area and along the southern scarp of the Diablo Mountains, where the base of the Hueco formation rests on eroded surfaces of the several pre-Cambrian formations, of the Van Horn formation and of Ordovician rocks at approximately the same elevation. Apparently the pre-Pennsylvanian land mass was reduced to a stage approximating peneplanation.

CARBONIFEROUS.

Carboniferous rocks have a widespread distribution in the area under consideration. The Pennsylvanian and Permian series are both well represented, but, as has been stated, the Mississippian is not present. The Pennsylvanian is represented by the Hueco formation, and to the Permian are for the present referred the Delaware Mountain formation and the Capitan limestone, and more doubtfully the Castile gypsum and the Rustler formation.

PENNSYLVANIAN SERIES.

HUECO FORMATION.—The Hueco formation consists mainly of massive gray limestone, but locally includes shales and sandstones. This formation has a wide distribution. It occurs on the northwestern flank of the Franklin Mountains and over a large part of the Diablo Plateau, being well exposed in the Cornudas, Diablo, Finlay and Hueco mountains, from which latter occurrence the formation is named. These areas are more or less distinct, and the formation in each has its peculiarities. However, there are few lithologic variations of mapable extent, and, since the faunas in all the occurrences have a distinct relationship, these rocks are classed as one formation.

On the northwestern flank of the Franklin Mountains a homogeneous massive gray to blue-black non-magnesian limestone is prominently exposed. Its top is covered by the unconsolidated deposits of the Mesilla Basin, and, although its base has not definitely been determined, it has a thickness of at least 5000 feet. The rocks dip steeply to the west and extend eastward to near the center of the range, where fossils apparently become less abundant. Here the rocks of known Carboniferous age are underlain by massive gray limestone in which no fossils have been found, but which strikes toward the Ordovician rocks exposed on the crest of the range farther south. The species[16] listed below were collected near the base of the Hueco formation near the center of the Franklin Range in New Mexico adjacent to the Texas boundary. The fossils were obtained from two stations close together in position and horizon.

[16]The identification of Carboniferous fossils in this report and comments on the faunas have been made by Dr. George H. Girty, who has freely used the materials collected by him in his trip of 1901. American Journal of Science, 4th Series, Vol. XIV, Nov., 1902, p. 363.

Triticites sp.
Chaetetes sp. nov. (?).
Fenestella sp.
Pinnatopora sp.
Orthotetes sp.
Productus cora d'Orb.
Productus, semireticulatus type.
Marginifera cf. M. Wabashensis Nor. and Pratt.
Squamularia (?) perplexa McChes.
Spirifer Rockymontanus Marcou.
Bellerophon sp. nov.
Orthoceras cf. O. Rushense McChes.

In the Hueco Mountains the Hueco formation consists entirely of homogeneous, massive, gray and non-magnesian limestone. In cliffs along the northwestern face of the mountains over 700 feet of the limestone are exposed, and from the dip it is estimated that the thickness is at least 3000 feet. The base of this limestone has not been definitely established, and its top is covered with wash concealing the connection with the outcrop of the formation in the Cornudas Mountains.

Collections of fossils have been made at numerous points in the Hueco Mountains, and some of them show much individuality of facies, corresponding, in some cases at least, to differences in horizon. One well-marked fauna was obtained at the crest of the escarpment 2½ miles northeast of Hueco Tanks. A preliminary list of the most important species obtained at this point is given below:

Fusulina, several sp.
Schwagerina (?) sp.
Axophyllum sp.
Fistulipora sp.
Septopora sp.
Schizophoria sp.
Enteletes cf. E. hemiplicatus Hall.
Orthotetes sp.
Productus cf. P. inflatus Tsch., *non* McChesney.
Productus cf. P. pustulatus Keys.
Productus cf. P. longus Tsch., *non* Meek, and P. porrectus Kut.
Productus, cf. P. irginae Stuck.
Productus, several sp. type of P. semireticulatus Martin.
Marginifera, cf. M. wabashensis Nor. and Pratt.
Spirifer, cf. S. marcoui Waagen.
Spirifer, cf. S. cameratus Morton.
Squamularia (?) sp.
Spiriferina, cf. S. cristata Schlot.
Seminula, cf. S. subtilita Hall.
Hustedia, cf. H. mormoni Marcou.
Camarophoria, cf. C. mutabilis Tsch.
Pugnax, cf. P. utah Marcou.
Dielasma, cf. D. truncatum Waagen.
Myalina sp.
Platyceras sp.
Naticopsis sp.
Omphalotrochus obtusispira Shumard.
Bellerophon sp.
Patellostium, cf. P. Montfortanum Nor. and Pratt.
Phillipsia sp.

From the top of a spur south of the road just as it emerges from the canyon, and immediately south of Cerro Alto, the species listed below were obtained. The horizon is probably several hundred feet above the one last mentioned and the identifications, as in other cases, are preliminary.

Schwagerina (?) sp.
Productus, several sp., type of P. semireticulatus Martin.
Marginifera, cf. M. wabashensis Nor. and Pratt.
Spiriferina, cf. S. cristata Schlot.
Ambocoelia sp.
Seminula mexicana Hall.
Pugnax, cf. P. utah Marcou.
Camarophoria, cf. C. mutabilis Tsch.
Dielasma, cf. D. bovidens Tsch., *non* Morton.
Aviculipinna sp.
Omphalotrochus (?), several sp.
Euomphalus (Phymatifer), cf. E. pernodosus Meek. and Worthen.
Naticopsis sp.
Trachydomia sp.
Trochus sp.
Loxonema sp.
Phanerotrema sp.
Bellerophon sp.
Cypridina sp.

From a flat-topped hill about 5 miles southeast of Cerro Alto the following forms were obtained. The fauna is related to the foregoing, but the horizon is probably somewhat higher.

Fenestella sp.
Polypora sp.
Septopora sp.
Rhombopora sp.
Meekopora sp.
Fistulipora sp.
Orthotetes (?) (Meekella ?) sp.
Chonetes sp.
Productus, cf. P. inflatus Tsch., *non* McChesney.
Marginifera, cf. M. wabashensis Nor. and Pratt.
Spiriferina, cf. S. cristata Schlot.
Ambocoelia sp.
Seminula, cf. S. subtilita Hall.
Hustedia n. sp.
Pugnax, cf. P. utah Marcou.
Camarophoria, cf. C. crumena Mart.
Dielasma cf. D. bovidens Tsch., *non* Morton.

The list below comprises species from a number of points in the Hueco Mountains, chiefly from the southern portion of the range. It will be observed that the fauna resemble that found near Cerro Alto, and not that obtained from the western scarp.

Fusulina sp.
Lithostrotion sp.
Archaeocidaris sp. nov.
Chaetetes smilleporaceus Milne Edwards & Haime.
Productus cora d'Orb.
Seminula Mexicana Hall.
Hustedia cf. H. Mormoni Marcou.
Hustedia n. sp.
Pugnax cf. P. utah Marcou.
Euomphalus (Phymatifer) n. sp.
Omphalotrochus obtusispira Shum.

And a number of other forms, especially many species of Gastropods.

The Hueco formation in the Cornudas Mountains consists of limestone similar to that in the Hueco Mountains. Though separated, the two areas are practically continuous, the limestone in the Cornudas being stratigraphically above much of that in the Hueco Mountains. Besides being present in the Cornudas, the limestone extends south to the Sierra Tinaja

Pinta and east to the Salt Basin. In this area the Hueco formation has been considerably cut by igneous rocks, but apparently not much metamorphism has occurred. Locally, as shown on the map, the limestone is unconformably overlain by rocks of Washita age. Toward the east in the direction of the generally low dip, the Hueco formation is covered by Pleistocene deposits of the Salt Basin, which prevent a determination of the relation of these Pennsylvanian rocks to the Permian in the Guadalupe Mountains. A sample of limestone from the Sierra Tinaja Pinta was analyzed by Mr. W. T. Schaller of the United States Geological Survey, with the following results:

Partial analysis of limestone from the Sierra Tinaja Pinta.

	Per cent.
Insoluble	.98
Alumina and iron	1.58
Lime	31.56
Magnesia	19.51

This analysis shows that the rock is almost a pure dolomite. The extent of these magnesian rocks has not been determined, but they may be limited to the vicinity of the igneous intrusion, for a limestone collected a few miles to the southwest showed only a trace of magnesium.

The following species have been obtained from the Cornudas Mountains:

Lithostrotion (?) sp.
Productus cf. P. Ivesi Newb.
Seminula cf. S. subtilita Hall.
Dentalium sp.
Naticopsis sp.
Trachydomia sp.
Euomphalus sp.
Omphalotrochus (?) sev. sp.
Soleniscus sev. sp.
Murchisonia (?) terebra White.
Phanerotrema sev. sp.
Bellerophon sp.
Patellostum sp.
Euphemus sp.

South of the Cornudas in the Sierra Tinaja Pinta the following forms were collected:

Lithostrotion (?) sp.
Archaeocedaris near A. biangulata Shumard.
Productus cf. P. semireticulatus, Martin.
Seminula Mexicana Hall.
Ambocoelia sp.
Dentalium sp.
Euomphalus sp.
Omphalotrochus obtusispira Shum.
Omphalotrochus sp.
Trochus n. sp.

And a number of small Gastropods chiefly of new species.

In the Finlay Mountains the development of the Hueco formation is unusual. Only about 300 feet of Carboniferous rocks are here exposed, and these consist of limestone, limestone conglomerate and shale. Different measurements are obtained in different exposures, but a generalized section is as follows:

Section of the Hueco formation in the Finlay Mountains.

		Feet.
6.	Massive gray limestone	75
5.	Limestone conglomerate	25
4.	Drab shale	25
3.	Massive blue limestone	25
2.	Massive limestone conglomerate	50
1.	Drab shale with bands of thin limestone	100

These rocks outcrop in an area of about 5 square miles in the Finlay Mountains, where they form the center of the dome. They are unconformably overlain by the Fredericksburg group of the Cretaceous.

The following species occur in collections from the Finlay Mountain section of the Hueco formation, the fauna probably belonging above that of the Hueco Mountains.

Fusulina cf. F. elongata Shum.
Orthothetina n. sp.
Chonetes cf. C. platynotus White.
Chonetes n. sp. near C. Flemingi Nor. and Pratt.
Productus sp.
Marginifera cf. M. splendeus Nor. and Pratt.
Marginifera cf. M. muricata Nor. and Pratt.
Pugnax cf. P. utah Marcou.
Richthofenia (?) sp.

In the Diablo Mountains the Hueco formation consists mostly of massive gray non-magnesian limestone, but there are variations. Sections along the east face of the mountains show several narrow beds of drab shale interbedded with limestone. In Marble Canyon, about 1½ miles southwest of the Figure 2 ranch headquarters, several dikes intersect the limestone and have metamorphosed it to marble. The latter is of various grades and colors. Some is black, some mottled, and there is a considerable quantity of homogeneous, fine-textured high-grade white marble. An analysis of this by Mr. W. T. Schaller shows the rock to be almost pure dolomite in composition.

Partial analysis of marble from Marble Canyon.

	Per cent.
Insoluble	.55
Aluminum and iron	None.
Lime	31.09
Magnesia	20.95

About 2000 feet of the formation are exposed in the escarpment of the Diablo Mountains, where the following section, 8 miles northwest of the Hazel mine, was made by Mr. W. H. von Streeruwitz.

Section of the Hueco formation in the Diablo Mountains about 8 miles northwest of the Hazel mine.

		Feet.
22.	Limestone with fossils	220+
21.	Shaly bituminous limestone	100

20.	Sandy shale	103
19.	Massive limestone with fossils	130
18.	Strata of limestone—each about 10 feet thick divided by shaly material—with fossils	100
17.	Yellowish gray shale	40
16.	Limestone with fossils	50
15.	Yellowish gray shale	2
14.	Limestone	20
13.	Massive limestone with a few fossils	50
12.	Yellowish gray shale	5
11.	Limestone with fossils	74
10.	Shaly bituminous limestone	11
9.	Limestone divided by flinty layers	50
8.	Shale	10
7.	Flinty stratified limestone with fossils	22
6.	Grayish limestone	5
5.	Breccia conglomerate of limestone	15
4.	Silicious limestone	1
3.	Clay shale	20
2.	Quartzite rock with interbedded pebbles, very coarse grained	10
1.	Quartzite material	15

Where the base of the formation is exposed in the southern Diablos and thereabouts, a coarse conglomerate composed of pebbles of limestone and fine red sandstone occurs. This basal conglomerate is not always present, but locally, as in the hill a mile west of Van Horn, it is prominent and attains a thickness of 100 feet.

Below the base of the Hueco formation, as exposed in the region about the southern Diablos, are older rocks, that were eroded to a peneplain before the deposition of the Pennsylvanian series. This is clearly shown by the fact that the Carboniferous rocks rest indifferently at approximately the same elevation on rocks of Ordovician, Cambrian and pre-Cambrian age, as previously mentioned.

The top of the Hueco formation in the Diablo Mountain region generally is not covered by other sediments, but about Black Mountain it is overlain by rocks belonging to the Washita group of the Cretaceous, and farther south, as shown on the map, rocks of Fredericksburg age rest directly on the Carboniferous.

The following species are from the Diablo Mountain area of the Hueco formation:

Fusulina elongata Shumard (?)
Archaeocidaris cf. A. biangulata Shum.
Rhombopora sp.
Septopora sp.
Schizophoria sp. nov.
Chonetes cf. C. platynotus White.
Productus cf. P. cora d'Orb.
Productus type P. semireticulatus Martin, sev. sp.
Squamularia? cf. S. (?) perplexa McChes.
Seminula cf. S. subtilita Hall.
Euconispira sp.
Omphalotrochus obtusispira Shum.
Euomphalus (Phymatifer) cf. Eu. pernodosus Meek. and Worthen.

The foregoing list comprises forms collected from several stations near the base of the formation, and the fauna is clearly related to those found in it in other areas. From near the top were obtained *Fusulina elongata* and *Hustedia* n. sp.

PERMIAN SERIES.

The Permian rocks include the Delaware Mountain formation and the Capitan limestone, and possibly the Castile gypsum and the Rustler formation, whose ages are not definitely known.

DELAWARE MOUNTAIN FORMATION.—The Delaware Mountain formation is composed essentially of sandstone and limestone, though locally a little shale also is included. At its greatest exposure the formation appears to be about 2300 feet thick, but the base is concealed by the Salt Basin deposits. The Delaware Mountain formation is prominently exposed at the base of the Guadalupe Mountains and in the Delaware Mountains, from which it is named.

At the base of the formation is a thin-bedded blue-black non-magnesian limestone of which about 200 feet are exposed. This rock is highly bituminous and gives a distinct odor on being struck with a hammer. This black limestone outcrops in the Guadalupes and in the northern Delawares, but it is not exposed farther south in the area mapped. Its fauna is closely allied to that in the overlying beds, and, considering the limited extent of the rock in the area mapped, it is thought best for the present to regard it as a member of the Delaware Mountain formation rather than as a distinct formation.

Above the black limestone the Delaware Mountain formation is variable. In the northern part of the region under consideration the formation is prevailingly sandy, while farther south it is chiefly calcareous. The variable character is apparent in the same cliff, where a massive bed of sandstone in one place forms a prominent bench and within a comparatively short distance becomes thin-bedded and inconspicuous. In one section little limestone may be exposed, while only a few miles away, along the same cliff, several beds may be present.

The following sections measured along the western scarp of the mountains show the general character of the Delaware Mountain formation:

Section of the Delaware Mountain formation and Capitan limestone along the scarp of Guadalupe Mountains at Guadalupe Point.

		Feet.
16.	Massive white limestone (Capitan limestone)	1700+
15.	Massive gray limestone	75
14.	Thin-bedded white sandstone	25
13.	Gray limestone (weathered buff)	50
12.	Thin-bedded drab sandstone	400
11.	Blue limestone	2
10.	Thin-bedded buff sandstone	425
9.	Massive white loose-textured sandstone	75
8.	Thin-bedded buff and drab sandstone	450

7.	Massive brown sandstone	10
6.	Thin-bedded brown sandstone	60
5.	Massive brown sandstone	4
4.	Thin-bedded brown sandstone	70
3.	Massive brown sandstone	4
2.	Thin-bedded buff and drab sandstone, almost shaly at the base	375
1.	Thin-bedded blue-black limestone, locally shaly toward the top	200

Section of the Delaware Mountain formation 3 miles south of the point of the mountain.[17]

		Feet.
17.	Dark shaly limestone	75
16.	Thin-bedded sandstone	50
15.	Dark shaly limestone	5
14.	Thin shaly brown limestone	10
13.	Dark-gray limestone	5
12.	Light-gray shaly sandstone	100
11.	Massive brown sandstone	8
10.	Thin-bedded shaly brown sandstone	50
9.	Heavy brown sandstone with some beds of shaly sandstone	150
8.	Thin-bedded shaly brown sandstone	50
7.	Massive white sandstone	15
6.	Thin-bedded shaly brown sandstone	100
5.	Massive whitish sandstone	50
4.	Thin-bedded shaly brown sandstone	75
3.	Dark-gray limestone	2
2.	Thin-bedded shaly brown sandstone	100
1.	Black shaly limestone	150

Section of the Delaware Mountain formation at the Hogue trail about 18 miles south of Guadalupe Point.

		Feet.
4.	Massive white sandstone	250±
3.	Thin-bedded blue limestone	450±
2.	Massive white sandstone	100±
1.	Blue limestone	200±

Besides being well exposed in the western scarp of the mountains, the Delaware Mountain formation outcrops along the eastern slope for a distance decreasing from 25 miles from east to west in the north to 8 miles in the south. The northern part of the slope is prevailingly sandy, while southward the rock is almost all limestone. When more detailed mapping of this region is done, several bands of sandstone and limestone will be differentiated in the northern part of the area around the headwaters of Delaware Creek.

The highland immediately north of the railroad, which constitutes

[17]Measured by Mr. E. H. Elder.

the southern end of the Delaware Mountains, is composed almost entirely of massive gray limestone, with only occasional thin beds of sandstone. Some sections show no sandstone at all. For instance, a section in the north end of the mountain, 5 miles north of Boracho, exposes 800 feet of massive gray limestone containing fossils characteristic of the Delaware Mountain formation, or, at least, different from those of the main Capitan limestone. It is tentatively assumed that the limestone so prominently developed in the southern portion of the Delaware Mountains represents a change in lithology in the Delaware Mountain formation, the sandy phase in the north becoming calcareous southward. The scarp was not followed throughout its extent, however, and this statement can not be made unreservedly.

The base of the Delaware Mountain formation is concealed, and its relation to the Hueco formation is indeterminable in this region because of the deep filling of the Salt Basin. The Delaware Mountain formation normally is conformably overlain by the Capitan limestone.

From the black limestone at the base of the Delaware Mountain formation the following species have been identified:

Enteletes sp. nov.
Meekella sp. nov. (?).
Seminula cf. S. Mexicana Hall.
Hustedia Meekana Shum.
Pugnax cf. P. Utah Marcou.
Pugnax, several n. sp.
Richthofenia Permiana Shum.
Aviculipecten sp.
Clinopistha (?) sp.
Pleurotomaria, several species, seemingly new.
Foordiceras n. sp.
Ammonoids, several species.
Phillipsia sp.

The fauna of the overlying sandstone is less abundant and is preserved for the most part in the form of casts. Some of the species collected in the vicinity of Guadalupe Peak are as follows:

Fusulina elongata Shum.
Productus cf. P. subhotridus Meek.
Productus sp. nov. (several).
Spirifer near S. cameratus Morton.
Seminula sp.
Pugnax cf. P. Utah Marcou.
Leptodus n. sp.
Richthofenia Permiana Shum.
Pteria (?) sp.
Aviculipecten (?) sp.
Acanthepecten (?) sp.
Pernipecten (?) sp.
Myoconcha sp. nov.
Pleurophorus sp. nov.
Laevidentalium canna White.
Pleurotomaria, several new species.
Bucanopsis sp.

From the limestone in the southern portion of the Delaware Mountains, the following species have been identified:

Fusulina elongata Shum.
Sponge spicules (abundant.)
Lophophyllum sp.
Striatopora (?) sp.
Fistulipora sp.
Acanthocladia n. sp.
Spirifer cf. S. Mexicanus Shum.
Spiriferina cf. S. cristata Schlot.
Seminula sp.
Hustedia Meekana Shum.
Dielasma n. sp.
Pugnax cf. P. Utah Marcou.

Bryozoa, Mesozoic types.
Orthotetes sev. sp.
Chonetes Perianus Shum.
Productus cf. P. pileolus Shum.
Productus cf. P. Popei Shum.
Productus sev sp.
Strophalosia sp.
Rhynchonella bisculcata Shum.
Leptodus n. sp.
Richthofenia Permiana Shum.
Bellerophon cf. B. crassus Meek and Worthen.
A number of small pelecypods and gastropods, many of them new.
Ammonoids, several species.

This fauna differs alike from that found in the sandstones of the Delaware Mountain formation farther north and that obtained near the middle of the Capitan limestone. It contains several species described by Shumard from what he calls the "dark Permian," a group of rocks which appears to correspond to the basal portion of the Capitan limestone. The same fauna was collected near Guadalupe Peak, chiefly from float fragments of limestone so situated that they must have had their source in either the upper portion of the Delaware Mountain formation or the lower part of the Capitan limestone. In either case they came from horizons higher than any represented in the list of fossils from the sandstones of the Delaware Mountain formation. The faunal evidence is defective, as the faunas of the upper Delaware Mountain and lower Capitan formations of the typical section are yet unknown, and the stratigraphic position of the collections from the Guadalupe Mountains, which contain the same association of species as those from the southern Delawares, is uncertain. However, the faunas seem to show that the limestones of the southern Delawares should be correlated with either the upper portion of one or the lower portion of the other of the two formations mentioned above. A comparison with even the known fauna of the Delaware Mountain sandstone is complicated by the circumstances that the latter shows an arenaceous or pelecypod facies, while the fauna of the limestone strata of the southern Delawares consists largely of brachiopods.

CAPITAN LIMESTONE.—The Capitan limestone is a massive white rock, which contains minor local variations, but is remarkably homogeneous in physical appearance. Chemically it is variable in composition; some analyses show the presence of considerable magnesium, while others indicate its almost complete absence, but the distribution of the magnesium throughout the formation has not been determined. The following analysis of a sample from near the top of El Capitan Peak by Mr. W. T. Schaller shows the rock there to be almost pure dolomite.

Partial analysis of rock from El Capitan Peak.

	Per cent.
Insoluble	1.01
Alumina and iron	.31
Lime	31.35
Magnesia	21.10

The Capitan limestone caps the Guadalupe Mountains, where its presence is commonly marked by perpendicular cliffs, often over 1000 feet in height (Plate IV, *A*). It also outcrops in a small area in the foothills a few miles southwest of Guadalupe Point.

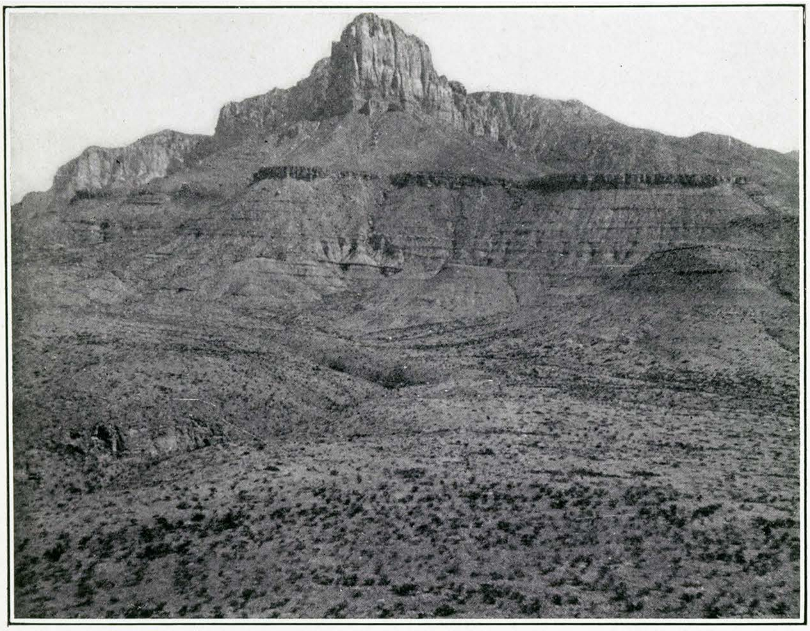
Eighteen hundred feet (barometrical measurement) of the Capitan limestone are exposed in an almost vertical section on the west scarp of the Guadalupe Mountains terminating in El Capitan Peak, from which the formation is named. This limestone lies conformably on the Delaware Mountain formation, but its top has not been found.

From the middle portion of the Capitan limestone an abundant and varied fauna has been obtained. The species not already described by Shumard are for the most part new. The following are some of the most abundant and interesting forms:

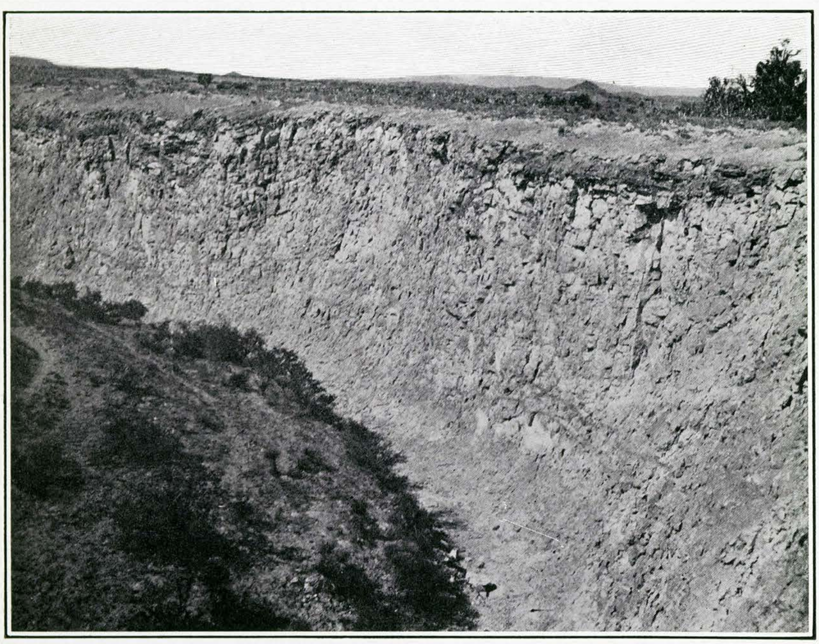
Fusulina elongata Shum.

Many sponges of new species.
Corals, few.
Acanthocladia n. sp.
Goniocladia n. sp.
Streptorhynchus n. sp.
Orthotetes sev sp.
Geyerella n. sp.
Orthothetina n. sp.
Chonetes n. sp.
Productus cf. occidentalis Newb.
Productus cf. subhotridus Meek.
Productus Popei Shum.
Productus Mexicanus Shum.
Productus sev. sp.
Marginifera (?) pileolus Shum.
Spirifer Mexicanus Shum.
Spirifer sev sp.
Martinia n. sp.
Squamularia (?) Guadalupensis Shum.
Ambocoelia n. sp.
Spiriferina Billingsi Shum.
Spiriferina sev. sp.
Hustedia Meekana Shum.
Pugnax Swallowiana Shum.
Rhynchonella (?) indentata Shum.
Rhynchonella (?) sev. sp.
Terebratuloids, sev. sp.
Leptodus n. sp.
Richthofenia Permiana Shum.
Schizodus securas Shum (?).
Aviculipecten n. sp.
Lima n. sp.
Camptonectes? sev. sp.
Streblopteria? n. sp.
Myalina squamosa Sow. (?).
Myoconcha n. sp.
A few small gastropods.

"The Carboniferous faunas of the Trans-Pecos region, especially the upper ones, differ widely from those of the Central and Eastern States. The fauna of the Hueco formation, however, is found with some modifications over most of the area west of the Rocky Mountains; but the remarkable group of fossils occurring in the Capitan limestone is only known in the Guadalupe Mountains. The fauna of the Capitan limestone differs to a marked degree from that of the Hueco formation, and was assigned to the Permian epoch both by Shumard, its original discoverer, and by Girty. The fact that the faunas of the Hueco formation in some respects strikingly resemble those of the *Spirifer marcoui* zone, the *Omphalotrochus whitneyi* zone, the *Productus cora* zone and the *Schwagerina* zone of the Carboniferous section of eastern Russia, which immediately underlie the typical Permian, seems to support the views of these authors. On the other hand, there are some matters of difference between the Russian faunas and those of the Hueco formation, part of which are points of agreement with the Capitan fauna. Thus, the Russian faunas, even the highest (that of the *Schwagerina* zone), seem aside from containing aspects not found in either, to combine features of



A. GUADALUPE POINT.
Capped by 1200 feet of Capitan limestone overlying 2000 feet of the Delaware Mountain formation.



B. CASTILE GYPSUM IN DRAW 8 MILES SOUTH OF SAYLE'S RANCH.

both the Hueconian and the Capitan faunas, features, moreover, which these formations do not possess in common.

"The American beds can hardly be looked on as being a mere expansion of the Russian series, since the Hueco, Delaware Mountain and Capitan formations combined have a thickness much exceeding 5000 feet, while the four zones recognized by Tschernyschew are considerably less than 1000 feet thick. In view, therefore, of the preponderating resemblance shown in the Hueco faunas and the differences in that of the Capitan limestone, the latter is retained under the title of Permian, and with it, provisionally, the Delaware Mountain formation."*

CASTILE GYPSUM.—The Castile gypsum is a massive white granular variety. It is comparatively pure, and a characteristic sample analyzed qualitatively by Mr. W. T. Schaller shows it to be of no unusual composition. Considering its great extent the Castile gypsum is remarkably homogeneous, yet it varies somewhat. On the surface generally it is disintegrated and earthy. In places it is grayish or dark in color owing to the presence of organic matter and at other places it is stained red by iron oxide. Locally, selenite is abundant. Some sections show occasional thin beds of banded gray limestone in the gypsum. Deposits of native sulphur are also associated with the Castile gypsum. The thickness of this formation is not known, but it is considerable. A well at the old sulphur works about 6 miles north of Rustler Spring shows a thickness there of a little over 300 feet, though the base of the gypsum is not known to have been reached. Good sections exposing sometimes 50 or 60 feet of gypsum are shown along Delaware Creek and Cottonwood Draw. Such sections commonly show the rock to be considerably cracked and joined (Plate IV, *B*). This gypsum is also cavernous, and there are many underground channels in it. A conspicuous one heads in a small draw about 6 miles southeast of Sayles' ranch. The opening of the cavern is circular, has a diameter of about 5 feet, and has been explored for a distance of about 1300 feet. This gypsum supports a peculiar variety of bunch grass (*Bouteloua breviseta*) called "yeso" grass, and also bears a stunted growth of junipers whose occurrence practically is limited to the gypsum.

The Castile gypsum outcrops in a belt between the Delaware Mountains and Rustler Hills, the width of which averages about 15 miles, though at the New Mexico-Texas boundary it is about 30 miles. This gypsum belt begins about 15 miles north of the railroad and extends into New Mexico. Within Texas the gypsum outcrops over 600 square miles. The name of the formation is derived from Castile Spring which is in the midst of the gypsum about 12 miles south of the State boundary.

The Castile gypsum along its western outcrop lies on little knolls and valleys of the underlying Delaware Mountain formation, indicating an erosional unconformity. Another evidence of unconformity at the base of the gypsum consists in the absence of the Capitan limestone. It appears that either the gypsum was deposited at or near the top of the Delaware Mountain formation as a lens which did not extend westward to intervene between the Delaware Mountain formation and the Capitan limestone in the Guadalupe Mountains, or that erosion removed the former southwestward extension of the limestone (the thickness of which

*G. H. Girty.

is unknown) before the deposition of the gypsum. The former supposition necessitates the correlation of the Rustler formation, which overlies the gypsum, with the upper part of the Delaware Mountain formation or with the Capitan limestone. But there is little to support this interpretation, and it is tentatively assumed that the Castile gypsum and the Rustler formation were formed after the deposition and erosion of a part of the Capitan limestone.

RUSTLER FORMATION.—The Rustler formation consists of a fine-textured white magnesian limestone and less abundant sandstone. The formation occurs in the Rustler Hills, in the dissected southwestern extension of the Rustler Hills between Cottonwood and Hurd's Pass "draws," and in a few isolated areas west of the hills.

The formation as here exposed averages about 200 feet in thickness and varies in composition. In the southern outcrops there is no sandstone, and the hills are capped by about 150 feet of massive gray limestone, which directly overlies the gypsum. Northward sandstone is present below the limestone. In the gap where Horseshoe Draw cuts through the Rustler Hills the following section was measured:

Section of Rustler formation in Horseshoe Draw.

	Feet.
3. Compact fine-textured gray magnesian limestone commonly pitted with small holes averaging the size of pin heads.....	50
2. Calcareous buff sandstone	100
1. Castile gypsum	50+

The magnesian limestone is practically dolomite, as shown by the fofowing analysis by Mr. W. T. Schaller:

Analysis of limestone in Rustler formation.

	Per cent.
Insoluble	6.43
Alumina and iron	1.77
Lime	28.39
Magnesia	18.77
Ignition	44.00
Total	99.36

The sandstone is frequently conglomeratic, containing rounded black and white pebbles of quartz up to the size of beans. It is also fine-textured. South of Horseshoe Draw, just before it enters the hills, the sandstone seems to lie on the eroded surface of gypsum, indicating an unconformity.

Though sought for in all of the exposures of the Rustler formation examined, only a few poorly preserved fossils were found. On one of the outlying areas of the formation on a low hill north of the road about 9 miles southwest of the mouth of Delaware Creek, a few fossils were found, which Dr. T. W. Stanton finds to have the form of *Mytilus*, but "they do not show generic character and might just as appropriately be referred to *Myalina,* which is especially common in the Permian."

Another specimen was collected about 5 miles southeast of Rustler Spring on the eastern slope of the hills. This was a Lamellibranch, but it proved to be indeterminable. Some poorly preserved plant remains were found in the sandstone about 3 miles west of Horseshoe Springs. These also are insufficient to determine the age, but, according to Dr. F. H. Knowlton, they may be Mesozoic.

From this fragmentary evidence it appears that the age of the Rustler formation is not known. The fossil shells indicate that the limestone is of marine origin, but whether of Permian or Mesozoic age is doubtful. A promising locality for the study of this question as well as to obtain light on the relations between the Pennsylvanian, Permian and Mesozoic of this region is in the Guadalupe and Sacramento mountains of Southern New Mexico.

Little is known of the distribution of the Permian sediments beyond the area mapped. They extend northward into the Sacramento Mountains of New Mexico, but how far has not been determined. No Permian rocks have been found west of the Salt Basin in the area studied, which suggests that this region may have been uplifted after the deposition of the Hueco formation. The extent of such uplift as well as the limit of the Permian sea are unknown.

"RED BEDS."

About 5 miles southeast of Maverick Springs is a small outcrop of red beds covering only a few acres at the most and not shown on the map. These rocks are entirely surrounded by the unconsolidated deposits of the Toyah Basin. No fossils have been found in them, and their stratigraphic relation is indeterminable. However, they are clearly younger than the Rustler formation. Red beds outcrop in the Pecos Valley in New Mexico, but little is known of them. The following section was measured here:

Section of "Red Beds," 5 miles southeast of Maverick Springs.

		Feet.
5.	Gypsum	
4.	Buff-colored fine-textured quartz sandstone	10
3.	Quartz conglomerate with a sandy matrix	2
2.	Buff-colored shaly sandstone	10
1.	Fine-textured red sandstone containing a few round green spots	25

JURASSIC.

MALONE FORMATION.—The Jurassic system in the area mapped is represented by a small outcrop about 1½ miles long and a quarter of a mile wide immediately northeast of Malone station. Here gray fossiliferous limestone is exposed in low hills that are surrounded by wash. The attitude of the limestone is obscure, but probably not more than 100 feet in thickness are exposed. The following species from this locality have been determined by Dr. F. W. Cragin:

Trigonia vyschetzkii Cragin.
Trigonia goodellii Cragin.
Cucullaea transpecosensis Cragin.
Cyprina streeruwitzii Cragin.
Lucina potosina Castillo and Aguilera.
Pleuromya inconstans Castillo and Aguilera.
Pholodomya tosta Cragin.

The entire fauna of more than 70 species has been described by Mr. Cragin in a paper soon to be published by the United States Geological Survey.

This outcrop is an outlier of the Malone Mountains just south of the railroad. The presence of Jurassic fossils in these mountains was announced by Mr. Cragin in 1897.[18] This occurrence is unique, for it is the only known Jurassic area in the entire Trans-Pecos country. The Malone Mountains have an area of only about 10 square miles and are separated from the adjacent highlands by the unconsolidated deposits of the Hueco Basin. The rocks are sharply folded and faulted, and their relation to the adjacent formations is not known.

There is little knowledge of early Mesozoic conditions in the area studied beyond that afforded by these Jurassic rocks. The absence of outcrops of Triassic and Jurassic age over much of the region may imply extensive land conditions. The Pecos Valley, however, apparently was submerged during at least part of the early Mesozoic. The Dockum beds, referred to the Triassic, outcrop at the base of the Staked Plains east of the Pecos River, but they have not been found in the area mapped. Likewise the red beds of the Pecos Valley are of pre-Cretaceous age.

CRETACEOUS.

COMANCHE SERIES.

The Cretaceous system is represented here by the Fredericksburg and Washita groups of the Comanche series. The Trinity group has not been recognized in this area, nor has the upper Cretaceous been found,* though rocks belonging to both of these ages occur not far to the south and west.

FREDERICKSBURG GROUP.—The Fredericksburg is separated into three formations: the Campagrande, the Cox and the Finlay, which are differentiated by their lithologic features. All these contain Fredericksburg fossils, but the faunas of the individual formations have not been collected with sufficient fullness to permit their paleontologic definition.

[18] Op. cit.

*With the possible exception that a few small areas of shale in the city of El Paso are of upper Cretaceous age.

Dr. T. W. Stanton has identified the following species from the Fredericksburg in this region:

Ostrea crenulimargo Roemer.	Exogyra texana Roemer.
Caprina occidentalis Conrad.	Requienia texana Roemer.
Radiolites davidsoni Hill.	Actaeonella doliam Roemer, etc.

Campagrande Formation. — The lowermost formation of the Fredericksburg group is composed of calcareous rocks that are well exposed in the Finlay Mountains, where, in the central part of the dome, they lie unconformably on the Hueco formation. At the base of the Cretaceous section is a limestone conglomerate about 25 feet thick composed of rounded pebbles of Carboniferous limestone averaging possibly about 2 inches in diameter. Above this are 350 feet of gray limestone, which is generally massive, but locally contains non-persistent thin-bedded limestone grading into shale. The formation is named from Campagrande Draw in the Finlay Mountains.

The Campagrande formation, in the area under consideration, outcrops in only a few places outside of the Finlay Mountains. A narrow bed of it is exposed on Triple Hill, 7 miles northwest of Sierra Blanca station, and several small outcrops which have been tentatively correlated with it on stratigraphic grounds occur north of Eagle Flat. The Campagrande formation is conformably overlain by the Cox formation.

Cox Formation.—The Cox formation consists of massive soft brownish sandstone, some intercalated gray limestone, and near the base a red drab shaly member. The formation averages about 600 feet in thickness, and is subject to variation in composition, so that no one section is typical. Sandstone predominates and composes probably nearly 500 feet of the formation. It is usually fine-textured, but there are some coarse beds of no great thickness containing quartz pebbles as large as marbles. Locally the sandstone is pitted with rounded iron stains the size of buckshot, which seem to be due to the weathering of pyrite nodules. In places the sandstone is cross bedded. The intercalated limestone and shale are usually thin bedded and are generally fossiliferous. The shaly member in the Finlay Mountains is about 100 feet thick.

The Cox formation is well exposed in the Finlay Mountains, where its stratigraphic position intermediate between the two other Fredericksburg formations in this region is clearly shown. It occurs in the southwestern scarp of the Diablo Plateau northwest of the Finlay Mountains, and the sandstones which are tentatively correlated with it on stratigraphic grounds outcrop on the hills immediately north of Sierra Blanca station and in a larger area 10 miles north of the railroad between Sierra Blanca and Eagle Flat stations. This formation is prominently exposed on Cox Mountain, 12 miles north of Eagle Flat, where it is overlain by 25 feet of olivine basalt, the only occurrence of basalt in the area studied. It is conformably overlain by the Finlay formation.

Finlay Formation.—The Finlay formation consists almost entirely of massive gray nonmagnesian limestone, but locally thin beds of brown sandstone are included. There are at least 300 feet of the Finlay formation exposed in this region, but the top has not been found.

In the area mapped the Finlay formation is not overlain by other sediments, but is commonly covered with a mass of residual soil and "wash" derived from the adjacent outcrops. This formation occurs in the outer rim of the Finlay Mountains, from which it is named. It occupies a large area in the broad flat north of the Finlay Mountains forming the southwestern part of the Diablo Plateau and is also exposed in the Sierra Blanca region.

WASHITA GROUP.—Rocks of Washita age are present as outlying masses in several localities. The thickness of the strata is not great and it has not been found practicable definitely to correlate the different exposures. They look much alike, being commonly buff-colored calcareous shale and thin-bedded limestone with occasional subordinate sandstone.

Dr. T. W. Stanton has identified the following species from these Washita rocks:

Nodosaria texana Conrad.
Diplopodia texanum (Roemer).
Pyrina parryi Hall.
Holectypus texanum Roemer.
Epiaster elegans (Shumard).
Terebratula wacoensis Roemer.
Ostrea quadriplicata Shumard.
Gryphaea mucronata Gabb.
Gyphaea washitaensis Hill.
Lima wacoensis Roemer.
Pecten texanus Roemer.
Schloenbachia leonensis (Conrad).
Schloenbachia shumardi (Marcou).

These rocks are most prominently exposed in the vicinity of Kent and San Martine as shown by the map. They are surrounded by the wash of the Toyah Basin and their base is not exposed, though in a well west of Kent Fredericksburg fossils are reported to have been found.[19] In the hills about Kent are exposed from 150 to 200 feet of horizontal thin buff limestone and interbedded shale and shaly limestone rich in fossils. Several smaller detached areas of Washita rocks also occur in the Toyah Basin northwest of Toyah, in the vicinity of Cottonwood Draw, and adjacent to the Pecos River.

Sediments of Washita age are associated with igneous rocks about Sierra Blanca, Black Mountain and the Cornudas. In the Sierra Blanca region along the west flank of the main peak and almost surrounding the smaller northerly ones are shales and limestones containing abundant Washita fossils. Northwest of the main Sierra Blanca peak the following section was measured:

Section of Washita rocks northwest of Sierra Blanca Peak.

	Feet.
4. Gray limestone	50
3. Drab shale	60
2. Drab limestone	21
1. Buff-colored sandstone	30

[19] E. T. Dumble and W. F. Cummings, The Kent Section, Op. cit.

In this vicinity also these Cretaceous rocks are practically surrounded by Pleistocene wash. The base of the section was not seen.

A good section of Washita rocks is exposed on the east side of Black Mountain. The base of the Cretaceous is covered by 50 feet of talus beneath which the Hueco formation outcrops. Above the talus 100 feet of cross-bedded rather coarse buff sandstone containing fragments of fossil wood occur, following which are 300 feet of alternating sandstone and limestone. The section is so covered by talus that a continuous exposure was not seen. These rocks abound in Washita fossils.

Surrounding the isolated peaks of the Cornudas Mountains in Texas and lying on the Carboniferous rocks with no earlier Cretaceous recognized beneath them are Washita shales and limestones. These extend in a very narrow band and are so covered with talus that the exposures are not at all conspicuous. The following section was measured between San Antonio Peak and Washburn Mountain:

Section of rocks of Washita age between San Antonio Peak and Washburn Mountain.

	Feet.
4. Buff-colored sandy limestone	2
3. Buff-colored shale	30
2. Buff-colored sandy limestone	30
1. Buff-colored sandy shale	50

Other detached rocks of Washita age occur in the vicinity of El Paso. A small mass lies at the southwestern end of the Franklin Mountains. Above El Paso are several areas on the Texas side of the Rio Grande and a larger outcrop west of the river. Four miles above the city, at the site of the proposed International dam, is an outcrop of flaggy limestone about 100 feet in thickness, below which are drab shales. These rocks are tilted and faulted. A few small areas of shale in which no fossils were found outcrop in the immediate vicinity of El Paso. Upper Cretaceous rocks occur west of the Rio Grande,[20] but no fossils of this age were found in the area studied.

At the beginning of Cretaceous time trans-Pecos north of the Texas and Pacific Railway appears to have been a land area that was gradually being submerged. This is suggested by the distribution of the rocks. Rocks of the Trinity group—lowermost lower Cretaceous—are well exposed south of the railroad, but do not occur in the area mapped. Instead, the Carboniferous is overlain by Fredericksburg rocks in the southern part of the field in the Finlay Mountains and by rocks of Washita age farther north in Black Mountain and about the Cornudas. In the Rio Grande and Pecos valleys within the area studied, the only known outcrops of Cretaceous age belong to the Washita group.

These Washita rocks are the youngest consolidated sediments that have been found in this area. To what extent rocks of upper Cretaceous age, which are known to occur nearby, are concealed beneath the basin deposits or have been removed by erosion is not known. Final uplift

[20]Stanton and Vaughan, The Cretaceous Section near El Paso, Op. cit.

in this region appears to have occurred toward the latter part of the Cretaceous or beginning of Tertiary time.

The greater part of the igneous rocks apparently are associated with this uplift, but there is little evidence concerning their age other than the fact that many of them intersect Comanche strata. In the Finlay Mountains there are a number of dikes ranging from a few feet to over a hundred in thickness, some of which can be traced for about a mile. They strike in different directions and cut both the Pennsylvanian and Fredericksburg series. The Sierra Blanca, Black Mountain, the Sierra Tinaja Pinta, the Cornudas Mountain and Cerro Alto consist of great masses of igneous rock which are flanked by sediments. At the base of the Sierra Blanca, Fredericksburg and Washita strata outcrop. In Black Mountain, in the Sierra Tinaja Pinta and in the Cornudas Mountains, the Hueco formation and sediments of Washita age are present contiguous to the igneous rocks; while Cerro Alto is surrounded only by the Hueco formation. In all of these occurrences more or less tilting of the adjacent sediments has accompanied the igneous eruptions.

QUATERNARY.

The Quaternary system has a widespread representation in the area mapped. Besides being developed in the Pecos and Rio Grande valleys Quaternary deposits cover the Hueco, Salt and Toyah basins, and also occur in wide areas in the uplands.

The components of the deposits are largely clay, sand and gravel, with which are locally associated gypsum and a calcareous deposit known as caliche. Excepting the caliche, which is compact, in general these deposits are unconsolidated; locally, however, they are cemented by calcium carbonate.

There are three main types of the Quaternary deposits: the alluvium of the river valleys, the more or less stratified basin deposits, and material composed of little transported detritus derived from the immediately underlying and adjacent rocks on the uplands. With the latter may be included the coarse detritus which flanks the highlands adjacent to the basins.

The alluvium of the Rio Grande and Pecos valleys consists for the most part of sand and clay which have been brought down by the rivers and deposited on their flood plains during stages of high water. With the sand and clay more or less organic matter is intermingled, and the river bottoms constitute valuable farming land which with irrigation yields good returns. More or less alkali, especially in the Pecos Valley, is present in these soils, but in general the quantity is not sufficient to interfere seriously with raising crops. These soils already have been reported upon.[21]

[21] A Preliminary Report on the Soils and Waters of the Upper Rio Grande and Pecos valleys in Texas. H. H. Harrington, Bull. No. 2, Geological Survey of Texas. 1890.

A Soil Survey in the Pecos Valley. T. H. Means and F. D. Gardner, United States Department of Agriculture Report, No. 64, 1900.

The basin deposits are unique and characteristic of the Trans-Pecos country. Logs of deep wells show that these basins are filled to great depths with unconsolidated material. Thus, a well near El Paso was sunk 2285 feet without striking bed rock. Another at Torbert in the Eagle Flat was put down 1165 feet in unconsolidated material and at Toyah there is a well 832 feet deep, in which bed rock probably was not struck.

A study of the logs of these wells given in the section on water resources shows that the basin deposits are in general composed of sand, clay and gravel, which occur both stratified and unstratified. All the basins are strewn with unstratified débris, derived from the adjacent highlands and spread over the plains by the torrential rains characteristic of this region. This unconsolidated generally unstratified material sometimes is called "wash." Over much of the area of the basins the "wash" effectively conceals the underlying deposits, but locally information concerning their nature and position is available. Exposed natural sections along the Hueco Basin adjacent to the Rio Grande show that these basin deposits are stratified and from east to west are practically flat. Similar sections are not exposed elsewhere in the area studied, but from well records in the Toyah Basin it appears that the deposits there also are stratified and are locally tilted. Little information exists concerning the underlying materials in the Salt Basin, but there is no reason to doubt that they, too, are stratified.

Much of the material in the basins apparently accumulated in water, but under what conditions remains to be determined. In the Salt Basin, associated with the prevailing fine-textured deposits are extensive accumulations of gypsum and salt, besides smaller amounts of borax, potash, strontium and lithium, which will be referred to under the description of Mineral Resources. Considering the closed nature of the Salt Basin and the extent and character of the deposits, it seems probable that a lake existed here. Shore lines were not observed, but they may have been destroyed by erosion or covered by the "wash" about the periphery of the basin.

The borders between the basins and the highlands are marked by bands of coarse detritus spread out apron-like at the foot of the hills, and composed of débris derived from them. In the vicinity of limestone areas this material is frequently more or less consolidated by calcareous cement. A conspicuous occurrence is north of Delaware Creek and east of the base of the Guadalupe Mountains, where for about 10 square miles the surface is capped with a deposit of coarse gravel and boulders. These consist of fragments of the Capitan limestone and Delaware Mountain formation, which have been washed down from the steep mountain side and have accumulated in a broad area. Locally this deposit is at least 100 feet thick.

On the uplands, especially on the Diablo Plateau, the underlying rocks are concealed by an accumulation of débris. This débris is "wash" derived from disintegration of the adjacent rocks. The constituent particles range from coarse to fine and have been more or less transported and rudely assorted. In the valleys this material is usually fine-textured and locally attains considerable thickness. Details concerning the Quaternary deposits will be given in the discussion of water resources.

The basin deposits are mapped as Quaternary. Practically all of the surface covering is Recent, being now in the process of formation, but the age of the underlying materials is not known throughout their extent. A considerable part, doubtless, is Pleistocene, but whether some of the basal deposits in the deeper basins are of Tertiary age is unknown.

STRUCTURE.

The geologic structure in general finds expression in northwestern-trending highlands and intervening basins. The highlands commonly are marked by scarps facing the basins and by slopes in the opposite direction. Igneous masses occur locally in rude alignment following the dominant structural trend. The basins are filled with flat or gently inclined unconsolidated deposits which conceal the underlying rocks. In detail the structure is complex and often obscure. Some of the more apparent facts were observed during the reconnaissance in 1903; but many details remain to be studied, and the facts themselves await correlation and explanation. Beginning at the east, the observed features will be briefly described.

The rocks beneath the Pleistocene deposits in the Toyah Basin are generally concealed. Proof that the underlying strata, at least locally, are disturbed is furnished by the small outcrop of red beds 5 miles southeast of Maverick Springs. These rocks have been folded into an irregular dome complicated by minor faulting. But the extent of this disturbed are a is not known.

Farther south the isolated remnants of Cretaceous rocks that are surrounded by the deposits of the Toyah Basin are, in general, low lying to flat, although there are local undulations. Thus, 2 miles west of Cottonwood windmills, 20 miles northwest of Toyah, the dip is S. 5° E., at an angle of about 10°, and the outcrop west of San Martine exposes a low anticline striking northwest and southeast; but on both flanks the rocks soon flatten out to their normal position.

In the Toyah Basin the structure of the unconsolidated material as a whole is not known, because of the lack of sections both natural and artificial. The artesian area at Pecos reveals a local southeastward inclination of these deposits and well records west of Arno suggest a low eastward dip, which will be referred to under the discussion of water resources; over the greater part of the basin there are no data.

In the Rustler Hills the structure is varied. In the northern part of the hills for several miles south of the Texas-New Mexico boundary, the rocks are irregularly bent into low wave-like folds which have apparently no common axial trend and dip from 20° to 40°. Some hillocks stand out as little domes, while others are quaquaversal synclines. There are also local faults with throws of only a few feet and various strikes. Farther south the folding becomes more regular, but less prominent. A cliff-making bed of sandstone exposed in Horseshoe Draw in the Rustler Hills shows a series of feebly developed folds whose axes trend parallel with the course of the hills—a little east of north. Four low anticlines and intervening synclines are developed in the 3-miles course of the "draw" through the hills. Still farther south the folding dies out and the rocks have a low easterly dip.

The structure of the gypsum belt is difficult to determine, because of the homogeneous nature of the deposits. There is no evidence, however, of much disturbance. Where the gypsum is capped by a bed of limestone the dip is clearly low to the east, corresponding with the general monoclinal trend farther west.

The Guadalupe-Delaware Mountains constitute a gently east-dipping monocline. There are minor variations in direction and angle of dip, but the general structure is uniform and pronounced. In the Guadalupe Mountains the dip varies from N. 60° E., to N. 80° E., and averages possibly 5°, though local dips as steep as 20° have been measured. Similar conditions prevail in the Delawares, except that the dips are less, and range from 2° to 5° N. 80° E. West of Luckett's ranch the dip is east to a trifle south of east, but changes again to the prevailing N. 80° E. at the southern end of the mountains. This easterly dip continues from the crest of the mountains eastward to the edge of the gypsum, and probably extends at least as far as the gentle plications in the Rustler Hills.

A local disturbance in the monocline is exposed in the valley of Chico Draw, about 4 miles west of White's ranch. There, in a belt about 100 feet wide, the rocks have been sharply folded and faulted on a small scale, the structure being clearly shown by a thin bed of limestone intercalated in the prevailing sandstone of the Delaware Mountain formation.

The escarpment that forms the western limit of the Guadalupe-Delaware mountains, and rises from 1000 to 5000 feet above the Salt Basin, suggests a fault. This escarpment was not followed its entire length, and only three sections were made across it. The presence of an anticline is shown in two of the sections and evidence from the third is inconclusive. In general a zone of disturbance accompanies the axis of folding and the eastern limb is considerably higher than that on the west.

Viewed from a distance, one sees only the scarp apparently rising directly above the plain, but a nearer view shows a belt of foothills at the base of the cliff. Immediately southwest of El Capitan Peak these foothills attain a considerable elevation, as shown by the map, but generally they are low. Locally they are 3 miles or more in width and expose outcrops of the Delaware Mountain formation, dipping southwesterly at angles of from 10° to 30°. In places, however, these rocks are concealed by débris and the cliff rises abruptly above the plain as at the base of the Hogue trail, 15 miles south of Guadalupe Peak, where there is no definite evidence of either folding or faulting (Section B).

An anticlinal fold is strikingly shown north of the road leading across Guadalupe Pass. A considerable thickness of westerly-dipping Capitan limestone is exposed here in high foothills. East of these is a débris-filled valley in which outcrops are rarely exposed, but occasional low hills of sandstone belonging to the Delaware Mountain formation likewise show westerly dips. East of the valley in which the anticlinal axis

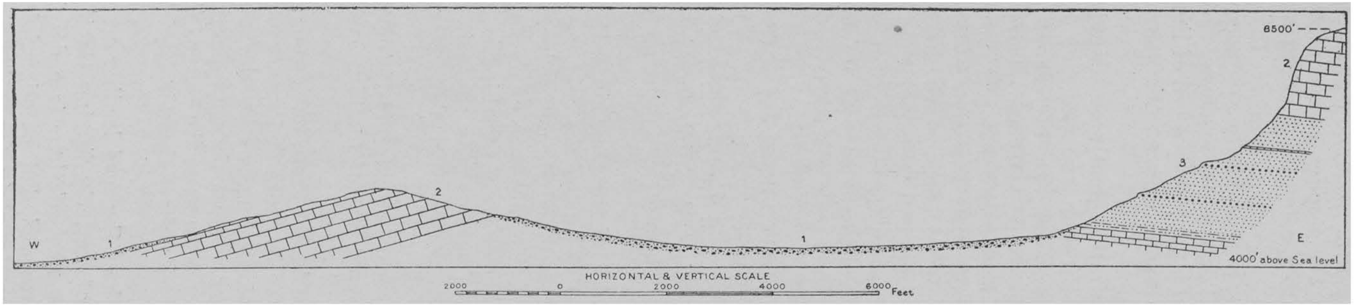


Fig. 1. Section west from Guadalupe Peak.
1. Pleistocene debris. 2. Capitan limestone.
3. Delaware Mountain formation.

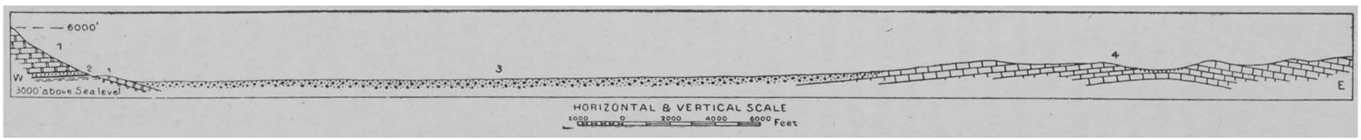


Fig. 2. Section across Salt Basin from the Diablo Mountains on the west to the Southern Delaware Mountains on the east, 22 miles north of the Texas and Pacific Railway.
1. Limestone of the Hueco formation.
2. Sandstone and shale of the Hueco formation.
3. Salt Basin deposits.
4. Limestone of the Delaware Mountain formation.

is located and forming the base of the mountains is the black limestone member of the Delaware Mountain formation having a low easterly dip, above which lie sandstones and limestones, the harder beds forming prominent benches on the slope. Capping all is the Capitan limestone in an almost vertical cliff over 1000 feet high. This cliff appears to be the product of erosion. The same fossil horizon has been recognized at points on the foothills and on the mountain at elevations that make it unnecessary to appeal to a fault. Fig. 1 brings out these relations. Faulting may be associated with this anticline, but if present, it is subordinate to the fold. There is need here for detailed work and for accurate determinations of altitude.

Farther north, toward the New Mexico boundary, the foothills are not separated from the main mountain by a valley and the western dip is steeper. Though the section was not studied here, the dips are very unsymmetrical on the two sides of the axis, and apparently the anticline has been faulted. In the Southern Delawares the scarp is less pronounced and a low symmetrical anticline is well exposed 20 miles north of Plateau in the valley that extends along the axis (Fig. 2).

Although the rocks underlying the Salt Basin are concealed by unconsolidated deposits, it may be conjectured that the structure is partly synclinal and that the basin is to a certain extent underlain by Permian strata—the continuation of those exposed in the foothills of the Delaware Mountains. If this be so, the Pennsylvanian strata in the Diablo Mountains indicate that the rocks rise again east of the west margin of the basin by folding or faulting, or both. Possibly the fault presently to be described may be only one of several step faults by which the Hueco formation has been uplifted, the others being concealed. The structure of the unconsolidated deposits of the Salt Basin is not known, but there is no reason to suppose they are much tilted.

A portion of the western side of the Salt Basin, marking the southeastern limit of the Diablo Plateau, is terminated by a normal fault which is marked by the east scarp of the Diablo Mountains. About 6 miles south of the "Figure 2" ranch headquarters a normal fault is shown by an east dipping "dragged" limestone abutting against practically flat sandstone which belongs stratigraphically below the limestone. The throw can not be measured, however, because the "dragged" limestone can not be correlated with any particular horizon of the upthrust limestone on the west (Fig. 2).

This fault seems to extend along the east cliff of the Diablo Mountains and to turn northwestward with the scarp. Ten or 12 miles from the turn the fault has disappeared and the axis of a low anticline marks what would be its continuation. This anticline is exposed about 5 miles southeast of the east end of Black Mountain. It is an unsymmetrical fold, whose southern limb is almost flat, while the northward dips are from 15° to 20°. This tilting is local and can not be traced far. Westward the rocks apparently flatten out and become covered with wash. Normal faulting has also occurred along the southern scarp of the Diablo Mountains, striking approximately east and west with the upthrow on the north. This fault is plainly apparent 7 miles north of Eagle Flat station, where, a short distance south of the scarp, Fredericksburg strata are horizontal and at the base of the scarp are tilted at an angle of 80°, abutting against flat-lying red sandstone in the scarp. A few miles east the updrag is not so steep, as shown in Pl. V, A. At these localities the throw can not be measured. At the base of the scarp, north of Allamoore, the relation of an outlier of flat-lying Carboniferous limestone south of the scarp to the same limestone in the scarp shows a throw of about 200 feet, as estimated by J. A. Taff.[22]

The structure of the pre-Cambrian area south of the Diablo Mountains is not satisfactorily known. The general strike is east and west, and the dips are steep to the south; but this area is complicated by obscure faults and folds. A promient local variation is shown in the knob known as Tumbledown Mountain, about 2 miles southeast of the Hazel mine. Here the pre-Cambrian rocks are folded into an almost complete quaquaversal syncline, with dips varying from 45° to 75°, and in the center of the fold there is a narrow dike striking northeast and southwest. The rocks of Tumbledown Mountain apparently are separated from the Ordovician rocks in the mountain on the east by a normal fault striking north and south with the upthrow on the west. These structural features originated at different times; the south-dipping structure is pre-Cambrian, while the faulting just referred to is at least post-Ordovician. This area demands detailed study.

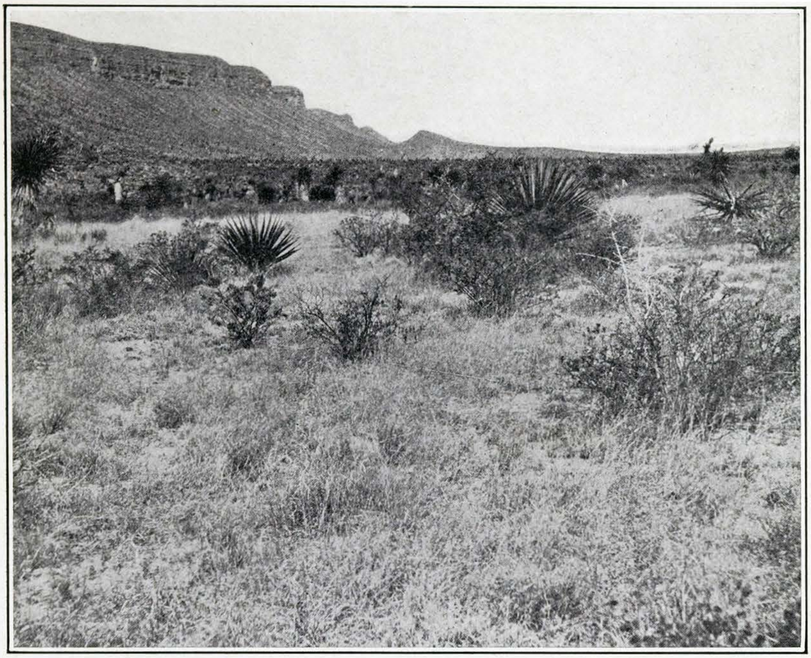
About Sierra Blanca the structure is also complicated. The hill north of the station is a westerly-dipping monocline with associated igneous intrusions at the southern end and a series of northeast-southwest step faults at the north. By these faults the Finlay limestone at the top of the hill is lowered about 300 feet to the level of the plain, as pointed out by Mr. Taff.[23] In the hill northeast of Sierra Blanca Peak rocks of the Fredericskburg group dip southwesterly at an angle of 45°, which appears to be partly due, at least, to the intrusion of a mass of igneous rock that forms the northeastern part of the hill. The Sierra Blanca, composed chiefly of igneous rocks, are partly flanked by flat-lying rocks of Washita age, but immediately southeast of the main Sierra Blanca Peak the Finlay limestone strikes into the mountain with a low southwest dip.

West of the Sierra Blanca the Quaternary deposits conceal important structural relations. The central ridge of the Malone Mountains, which lie immediately south of the railroad between Malone and Finlay, marks a sharp syncline which is east of a broad anticline and west of an obscure anticline which is complicated by faulting. These folds strike about N. 15° W. The Malone Mountains are composed of Jurassic rocks whose relations to contiguous formations are completely hidden. That this folding is continued northwestward, is indicated by the low-lying outcrop of Fredericksburg rocks, almost concealed by the wash, 3 miles west of the Finlay Mountains. These rocks are folded into a narrow anticline, with dips of 30° S. E. and 60° N. E.

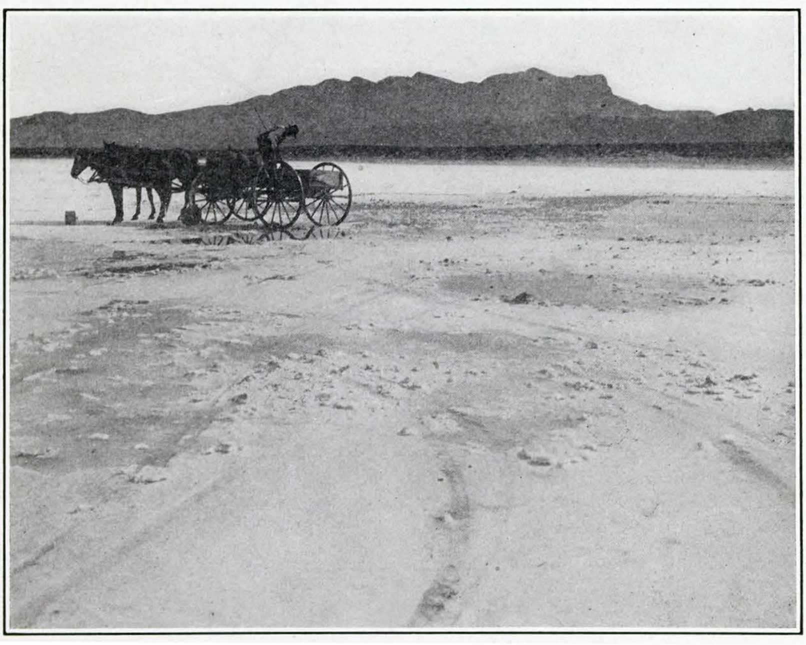
The structure of the Finlay Mountains is a rude dome, which topographically is well shown by outlying hills of Fredericksburg sandstone and limestone dipping away on all sides from the central area of Carboniferous rocks and girdling them in a crude ellipse. The dips of the

[22]Unpublished Notes made in 1890.

[23]Second Ann. Rept. Geol. Surv. of Texas, 1890, p. 716.



A. SOUTHEASTERN SCARP OF DIABLO MOUNTAINS,
seven miles northeast of Eagle Flat station.



B. "SALT LAKE" IN THE SALT BASIN
Guadalupe Mountains in the background.

dome range from 5° to 20° and average about 10°. In the northeastern part the dips flatten out where the Finlay Mountains merge into the Diablo Plateau. The Finlay Mountains have been intruded by a number of dikes striking in different directions, and although there is no definite proof, it is possible that the dome structure has resulted from subterranean igneous movement.

The Diablo Plateau throughout its extent is underlain by flat or low-lying rocks. Its southern end is underlain by the low west-dipping limestone of the Diablo Mountains, and the northward extension of these rocks with the eastward extension of the low east-dipping limestone of the Hueco Mountains forms the eastern and central floor of the plateau. Black Mountain, the Sierra Tinaja Pinta, and the Cornudas Mountains, extending along the eastern side of the Plateau, are largely composed of igneous rocks of post-Washita age, which locally have tilted the adjacent sediments. The southeastern limit of the Diablo Plateau, it has been mentioned, is marked by faulting along the scarp of the Diablo Mountains.

On the southwest the Diablo Plateau is marked by the practically flat area of Finlay limestone. The southwestern escarpment of the plateau northwest of the Finlay Mountains was not studied. It may be a simple erosion scarp protected by the overlying massive limestone, but near the Finlay Mountains there are local exposures of southwest-dipping rocks at the base, which are indicative of either faulting or close folding. This latter structure strikes with the dominant northwest-southeast trend.

The Hueco Mountains constitute in the main an east-dipping monocline with anticlinal structure locally developed contiguous to the scarp that faces the Hueco Basin. In the northern part of the mountains the dip is almost due east, ranging from 10° to 15° near the scarp. Eastward the dips gradually decrease and low-lying limestone underlies the northwestern part of the Diablo Plateau. In the southern part of the

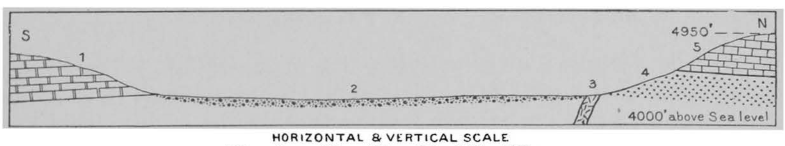


Fig. 3. Section of southern end of Hueco Mountains, 17 miles northeast of San Elizario.
1. Limestone of Hueco formation.
2. Pleistocene sand and gravel.
3. Granite dike.
4. Bliss sandstone?
5. El Paso limestone.

Hueco Mountains the inclination of the rocks is northeasterly. Along the scarp at the southern end a fault is suggested by the escarpment, by the presence of a dike parallel with the scarp, and by the fact that to the south Carboniferous rocks have the same elevation as Ordovician rocks exposed in the scarp. The dips are anticlinal, however, and it is possible that the main structure is due to folding, although there may also be associated faulting (Fig. 3). Low west dips are exposed in the outlying hills west of the mountains, but the axis of folding is concealed by unconsolidated deposits. A group of igneous rocks is exposed in the vicinity of Hueco tanks adjacent to the axis of folding. Here, too, faulting may be associated with the folding, but the presence of a fault has not been determined. There is a small area of considerable disturbance about 6 miles south of Hueco tanks, but the details have not been studied. Local tilting of the Hueco formation occurred incident to the eruption of the igneous rocks of Cerro Alto.

The structure of the unconsolidated deposits of the Hueco Basin is not definitely known, but the incomplete information furnished by wells and the sections exposed north of the railroad indicate that these deposits are but little inclined from horizontal. Their attitude has a bearing on the water supply and will be referred to again.

The position of the bed rock beneath the Hueco Basin is absolutely un-

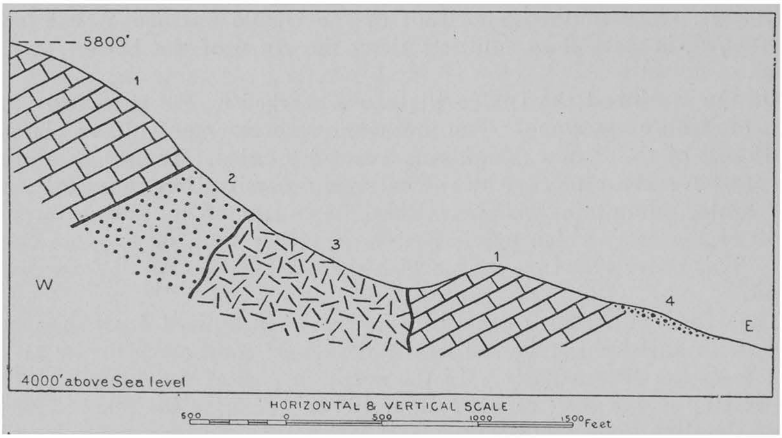


Fig. 4. Section of the southeastern end of the Franklin Mountains, 4 miles north of El Paso.
1. El Paso limestone. 3. Granite.
2. Bliss sandstone. 4. Pleistocene debris.

known. The west dips of the outlying hills of the Hueco Mountains and the probable identity of the Ordovician and Cambrian rocks in the Hueco and Franklin mountains suggest folding beneath the basin. This hypothetical structure would strike approximately parallel with the linear extent of the basin and would be synclinal on the east beneath the greater part of the basin and anticline on the west contiguous to the Franklin Mountains. It is possible that this supposed anticline east of the Franklin Mountains is faulted—the fault being a continuation of that believed to extend east of the San Andreas Range in New Mexico. This, of course, is entirely conjectural.

The general structure of the Franklin Mountains is a steep-dipping-faulted monocline. The dips are westerly and range from 20° in the southern part of the mountains to 60° near the State line. Pleistocene deposits completely surround the range so that it stands out alone, and its relation to other rock masses is concealed. The fact that the outlying areas of Silurian rocks east of the ridge, one at the State line and the other west of Fort Bliss, are east of the Ordovician and dip westerly, implies normal faulting of considerable throw, but the exact stratigraphic relations of these rocks have not been determined.

The existence of a fault at the southeastern extremity of the Franklin Mountains about 3 miles north of El Paso is definitely proved. There the rocks all dip west at an angle of about 20°. On a low ridge at the eastern base of the mountains Ordovician rocks outcrop, while up the slope to the west Cambrian and Ordovician rocks occur. The same Richmond horizon has been recognized on both sides of the fault. A belt of granitic rock outcrops along the fault plain. This is a normal fault; the strike of the fault plain is north and south; the hade is eastward, and the throw approximates 2000 feet (Fig. 4).

The age of this fault is not known, except that it is post-Ordovician. That near-by faulting in this general trend, however, has occurred recently is shown by displaced sands and clays exposed in a sand pit in the northern part of the city of El Paso. A section of about 50 feet is exposed in this pit. The upper part consists of horizontal coarse sand and gravel, unconformably below which, the contact not being well shown, are fine sands with streaks of clay. These lower beds are tilted about 10° to the southwest and are faulted, the displacements being emphasized by the streaks of clay. This is a case of normal step faulting. The hade is easterly about 15° and the downthrow is about 2 feet in an opposite direction from the dip of the strata.

MINERAL RESOURCES.

INTRODUCTORY.

The mineral resources of the region here discussed are varied. They include tin, silver and copper in amounts known to be valuable, and the presence of gold, lead and other metals in small amounts is known. Coal has been found recently. Gypsum, salt, petroleum and native sulphur occur in greater or less amounts. Building stones, marbles, limestones and clay are found in quantity, and the presence of underground water is widespread.

The occurrence of tin in the Franklin Mountains, 10 miles north of El Paso, has been described by Mr. W. H. Weed,[24] and Mr. W. H. von Streeruwitz has described the Hazel mine,[25] situated 10 miles northeast of Allamoore, which is reported to have produced considerable silver and copper. No mining and only a little development work is now being done on the metals in this region, though from time to time active prospecting is carried on in the Franklin, Finlay, Diablo, and Guadalupe mountains, where valuable strikes may yet be found. In the Guadalupe Mountains adjacent to the State line promising copper prospects have been recently reported. The ore is said to be copper carbonate in fissure veins in the Permian limestone.

During the reconnaissance in 1903 lack of time prevented the study of the occurrence of any of these substances except water. A few notes, however, were made on salt, petroleum and sulphur which are attracting attention. Coal has been found since field work closed.

COAL.

Coal was found 8 miles northeast of Fort Hancock in a well sunk for water, in February, 1904. This well was started in the unconsolidated deposits along the southeastern edge of the Hueco Basin and a bed of coal reported to be 6 feet thick was struck at a depth of 244 feet, as shown by the following log:[26]

[24]El Paso Tin Deposits, Bull. No. 178, U. S. Geol. Surv., 1901.

[25]Third Ann. Rept. Geol. Surv. of Texas, 1891, pp. 387-389.

[26]Log furnished by Dr. Wm. B. Phillips.

Log of well 8 miles northeast of Fort Hancock.

	Thickness	Depth feet.
Gravel and clay	6	6
Clay	154	160
Red sandstone	38	198
Limestone	5	203
Red sandstone	9	212
Yellowish limestone	18	230
Black shale	14	244
Coal	6	250
Blue shale	8	258
Black shale	17	275

Dr. Phillips examined some of the fragments brought up by the drill and found that they will coke. Beyond this, nothing is now known, though the occurrence soon will be further exploited.

Coal is known to occur at several localities in trans-Pecos Texas: It has been reported from Eagle Springs;[27] between Sierra Barda and the Rio Grande;[28] between Alpine and Paisano Pass;[29] on the east and south sides of the Chisos Mountains;[30] and near San Carlos. In all of these occurrences, so far as known, the age of the coal is upper Cretaceous, but only the San Carlos[31] field has been studied in detail. Coal has been found at several localities in New Mexico, but in all of these the coal is of Laramie age.

Little can be predicted concerning the coal north of Fort Hancock because of its hidden occurrence. It should be noted, however, that at the nearest outcrop of consolidated rocks to the southeast, 5 miles away, the strata are sharply folded and it is possible that disturbed conditions will be found at the present locality which is approximately along the strike of the folding.

SALT.

The presence of salt in the Salt Basin has long been known to the Mexicans, who, in the early days of the occupation of the country, are said to have traveled for it from distant parts of Chihuahua. The first wagon road to the deposit, however, was not built until 1863. Not long after its construction the salt was "located" and claimed, and an effort was made to collect a charge for the salt, which formerly was free to all. This provoked trouble that was made an issue in a personal feud between two politicians, and finally, in 1877, resulted in riot and bloodshed

[27] B. F. Hill, Bull. No. 2, Univ. of Texas Mineral Survey, 1902.

[28] Von Streeruwitz, W. H., Fourth Ann. Rept. Geol. Surv. of Texas, 1893, p. 175.

[29] Op. cit.

[30] Vaughan, T. Wayland, Bull. No. 164, U. S. Geol. Surv., 1900, pp. 73-95.

[31] Vaughan, Op. cit.

at San Elizario. Quiet was restored only by the intervention of the United States army.[32]

This deposit of salt is situated on the west side of the Salt Basin, about 15 miles southwest of El Capitan Peak and a little more than 50 miles north of Vanhorn. The deposit is locally known as the salt lake. It occupies a slight depression, and is one of several so-called lakes similarly situated in this part of the Salt Basin (Plate V, B).

Unconsolidated, impure gypsum forms the floor of most of these lakes and surrounds and connects them. Borax and potash have been found in one of the dry lakes. Strontium occurs in the gypsum that surrounds the salt lake, and there are traces of lithium in the deposits. Outside the area occupied by these depressions, the materials of the Salt Basin generally are clay and fine sand, and toward the margin the surface is strewn with coarser débris from the contiguous highlands.
Salt Basin generally are clay and fine sand, and toward the margin the surface is strewn with coarser débris from the contiguous highlands.

Although some salt occurs in a few of the other lakes, only one is known to contain it in important quantities. This is roughly elliptical in outline and has an area of about 45 acres. Viewed from a distance, it presents the appearance of a pond covered with ice or snow, so white is the layer of salt on its surface.

During the dusty, dry season the salt becomes impure, but after a rain, and especially in localities where the surface salt has been lately removed, beautiful hopper-shaped crystals are formed. An analysis of some of these, by S. H. Worrell of the University of Texas Mineral Survey, gave the following results:

Analysis of salt crystals.

	Per cent.
Chlorine	59.5
Sodium	38.6
Calcium	0.1
Magnesium	0.2
Sulphur tetroxide	1.2
Water	1.0
Total	100.6

The analysis shows that the crystals are almost pure halite, mixed with small amounts of calcium and magnesium sulphates.

No wells have been sunk to test the character of the underlying deposits, but a shallow hole shows the following section:

	Inches.
Salt	1
Gypsiferous sand	¼
Black clay with sulphur smell, impregnated with salt	6
Green-drab clay	24

A qualitative analysis of these substances, by Mr. S. H. Worrell, shows

[32] House Ex. Doc. No. 93, 45th Congress, Second Session, El Paso Troubles in Texas, 1878.

the presence of silica, alumina, lime, magnesia, soda, sulphur trioxide, carbon dioxide, and traces of potash and lithium, but no borax. Borax, however, occurs in at least one locality near by. An evaporation crust on a lake about 2 miles southeast of the salt lake examined by E. M. Skates of El Paso has the following composition:

Analysis of crust of lake.

	Per cent.
Insoluble; sulphates of calcium, magnesium and sodium	73.0
Sodium chloride	18.3
Borax	8.7
Total	100.0

No test was made for potash. From this analysis it appears desirable to further prospect in this locality.

The layer of salt which covers the surface of the lake is said occasionally to attain a thickness of from 4 to 6 inches, but measurements made in 1903 show an average of only about 1 inch. This is the commercially valuable deposit, for the crystals of halite referred to above are comparatively rare. The salt is grayish white, coarsely crystalline to granular and deliquescent. Locally there is often an admixture of windblown impurities which are common on the surface of the deposit. An analysis of a typical specimen, by Mr. S. H. Worrell, is as follows:

Analysis of common salt.

	Per cent.
Silica	0.6
Alumina	0.6
Iron	trace.
Magnesia	trace.
Lime	trace.
Potash	none.
Sodium sulphate	1.4
Sodium chloride	97.3
Total	99.9

The ground-water level here is very near the surface. The test hole, above referred to, rapidly filled with water, which contained considerable gas, apparently hydrogen sulphide. An analysis of this water, by Mr. S. H. Worrell, is as follows:

Analysis of Water.

	Parts per 1,000.
Silica	none.
Alumina	none.
Iron	noue.
Lime	none.
Magnesium	6.5

Sodium	27.9
Potassium	trace.
Chlorine	52.7
Sulphur tetroxide	12.8
Total	99.9

When the surface layer of salt is removed, its place is taken by this brine, which evaporates and deposits salt, so that, within a few weeks after stripping an area, salt completely replaces that which was removed. The supply is popularly believed to be inexhaustible.

These facts imply that the salt is derived from an underground source, either from disseminated salt or from a bed of salt with which the ground waters come in contact. The depth below the surface and the extent of such deposits are entirely conjectural.

This salt is extensively used by ranchmen, some of whom come from Fort Davis, a distance of over 100 miles. Considerable salt from the lake is also freighted to the pan amalgamation works at Shafter, 150 miles distant. The salt is not sold by weight, but by the load; a 2-horse load costs $1, and a 6-horse load $3. No careful records are kept of the amount of salt hauled away, but certainly immense quantities have been used, and apparently there is as much in sight as there was forty years ago.

PETROLEUM.

The presence of petroleum in commercial quantities in parts of Trans-Pecos Texas—in Pecos, Reeves and eastern El Paso counties—has been suspected for several years.[33] Indications are numerous. Bituminous limestones, sandstones and shales that give a strong odor on being struck with a hammer outcrop in many places. The occurrence of globules of oil in the water from various wells, of a few oil seeps, and especially of small quantities of petroleum in oil prospects, tend to confirm the suspicion that oil in paying quantities actually exists here. But as yet this hope has not been realized.

In Bulletin No. 2 of the University of Texas Mineral Survey, Dr. Phillips calls attention to the presence of oil and asphalt in small quantities near Fort Stockton. Since the publication of that bulletin a well 1200 feet deep has been put down in search of oil in that vicinity, and though a little petroleum and gas and considerable sulphur were reported, oil in paying quantities was not found. The well struck highly mineralized artesian water, which flows about 25 barrels a day. The log of this well, furnished by W. W. Turney through Dr. Phillips, is given below. The geology of the surrounding area has not yet been studied.

[33]Phillips, W. B., Texas Petroleum, Bulletin No. 1, University of Texas Mineral Survey, 1901.
Phillips, W. B., Sulphur, Oil and Quicksilver in Trans-Pecos Texas, Bulletin No. 2, University of Texas Mineral Survey, 1902.
Hill, R. T., The Beaumont Oil Field and Notes on other Oil Fields of the Texas Region, Journal of the Franklin Institute, Vol. CLIV, page 226, 1902.

Log of artesian well near Fort Stockton, Section 19, Block 140.

	Feet.
Black loam	0 to 10
White marl	10 to 22
Honey-comb gravel	22 to 40
Quartz rock carrying oil	40 to 200
Quartz rock richly impregnated with sulphur	200 to 250
Quartz rock carrying oil and sulphur	250 to 400
Quartz rock richly impregnated with sulphur	400 to 525
Brown sandstone	525 to 540
Quartz rock carrying crystallized sulphur	540 to 600
Brown sandstone carrying oil	600 to 610
White and blue quartz rock	610 to 620
Brown sandstone carrying oil	620 to 630
Blue sandy limestone	630 to 640
Brown sandstone carrying oil	640 to 665
Impure limestone carrying oil	665 to 685
Black sandstone carrying oil and gas	685 to 920
Impure limestone	920 to 940
Black sandstone	940 to 959
Blue mud	959 to 960
Black sandstone carrying oil	960 to 975
Light blue sandstone	975 to 1005
Black sandstone carrying oil	1005 to 1025
Light blue sandstone carrying gas	1025 to 1035
Black sandstone carrying some oil	1035 to 1050
Light blue sandstone carrying gas	1050 to 1065
Black sandstone	1065 to 1070
Brown sandstone	1070 to 1080
Blue sandstone	1080 to 1120
Brown sandstone	1120 to 1130
Blue sandstone carrying oil	1130 to 1200

Another unsuccessful deep well was sunk, in search of oil, about 4 miles west of Carlsbad, New Mexico, in 1902. A log was not kept, but the well was sunk to a depth of 1500 feet and only a little gas and oil were reported.

In 1855-'57, Capt. John Pope put down two wells in search of artesian water, about 10 miles east of the mouth of Delaware Creek. The deepest was sunk 1050 feet, apparently mostly through red beds. No hydrocarbons were reported, and the undertaking was a failure.

In the region with which this paper is especially concerned a number of wells have been drilled in this oil belt. The deepest of these, the Aden well, on the east slope of the Delaware Mountains, 9 miles northwest of Lone Man Mountain, was sunk in 1902 in search of water. No signs of oil were reported from this well, which was put down 916 feet mostly in limestone of the Delaware Mountain formation.

Another deep hole is the artesian well at Toyah, which is 832 feet deep, and is reported to have gone all the way through unconsolidated materials.

A number of wells have been drilled in the unconsolidated deposits of the Toyah Basin, in the immediate vicinity of Pecos City, where artesian water is found at a depth of between 200 and 300 feet. It is reported that, if the water from these wells be allowed to stand a considerable time, traces of oil will appear. In 1901, a well was drilled 6 miles southeast of Pecos, to a depth of 282 feet, in the basin deposits. A small amount of gas was struck at 155 feet; traces of oil were found at 217 feet, and several other traces of oil were encountered between 240 and 282 feet.

Petroleum has been found also in two other wells in the Toyah Basin, —the Casey and Ross wells, respectively 12 and 15 miles northwest of Pecos. The quantity is so small that the oil is cased off and the wells are used for watering stock. Traces of oil are also found in the Tinnin well, near Cottonwood Draw, about 20 miles northwest of Toyah; in the Burnt Spring, northwest of Toyah, and at a few other localities. In spite of these various indications, very little oil had been found in trans-Pecos Texas, until early in 1903, when J. D. Leatherman reported oil about 15 miles northwest of Toyah, in the Toyah Basin. This oil is said to occur in unconsolidated rock, but it has not yet been regularly removed and the true yield of the well has not been determined. The well went through 20 feet of surface material, mostly gypsum, 20 feet of gravel, and 150 feet of bluish clay containing a few sand streaks. Oil is reported to have been struck at 170 feet, which rose to within about 30 feet of the surface. Considerable gas accompanies this oil.

A limited quantity of oil from the Leatherman well is for sale at Pecos City, where it is used for greasing windmills. An analysis of this oil by O. H. Palm, of the University of Texas Mineral Survey, follows:

Analysis of oil from 15 miles northwest of Toyah.

Specific gravity: 20° C (68° F.), .9090, equivalent to 24° Beaume. Barometer: 29.2 inches.

Color: Dark brown. Odor: sweet.

Viscosity: Engler test—20° at 25° C.—73° F.

Cooling test: Oil flows at minus 16° C.—3° F.

Flash point: 74° C.—165.2° F. Burning point: 110° C.—230° F.

Heating power: 19,440. B. T. U.=Calories: 10,800 on water free oil.

Distillation yielded the following fractions (29.2 in. pressure):

No.	Temperature. Centigrade.	Temperature. Fahrenheit.	Percentage by volume.	Specific gravity.	Beaume.	Color.
1	125°-150°	257°-302°	6.10	.7404	59	Colorless.
2	175°-200°	347°-392°	1.20	.7590	54.5	Straw yellow.
3	225°-250°	437°-482°	7.80	.8360	37	Light yellow.
4	250°-275°	482°-527°	8 20	.8543	34	Light yellow.
5	275°-300°	52.°-572°	7 40	.8620	32	Yellow.
6	325°-350°	617°-662°	50.00	.8843	28	Pale red.
Residue: 14 per cent by weight			14.00			Black asphalt.
Loss			5.30			
Total			100.00	Naptha (fraction 1).......6.10 per cent by vol. Burning oil (2, 3, 4, 5) ...24.60 per cent by vol. Heavy oil (6)..................50 00 per cent by vol.		
Sulphur: 1.00 per cent.						

The heavy oil has a very low viscosity, due to the fact that the crude oil decomposed rapidly during the distillation. A sickening odor was given off during the entire fractionation.

In the fall of 1903, a well was sunk by a California company about 1¼ miles southwest of the Leatherman well, with poor results. The log of this well is as follows:

Log of California Company's Well No. 1.

	Thickness feet.	Depth feet.
Surface, mostly gypsum	27	27
Gravel	40	67
Coarse gravel, water at base	4	71
Blue clay	9	80
Hard sand	45	125
Blue clay	14	139
Brown clay	95	234

Although little or no oil was found, it was decided by those in charge to make a decisive test in this vicinity, and a new site was chosen near the other two wells. By January 15, 1904, the drill had reached a depth of 272 feet, and had passed through the following material:

Log of California Company's Well No. 2.

	Thickness feet.	Depth feet.
Surface, mostly gypsum	18	18
Gravel	17	35
Blue clay with thin streaks of sand, oil-bearing (considerable sulphur water was found in gravel at 203 feet)	179	214
Solid rock, chiefly sandstone but with streaks of thin limestone; also containing some oil	58	272

The oil found in this well is reported as similar to that in the Leatherman well, but the quantity is small and has not been determined.

The Leatherman and California oil wells are situated in the Toyah Basin, in the midst of a broad, very gently undulating flat. Cottonwood Draw, occupying a scarcely perceptible swale, is near by. In the immediate vicinity of the wells, and extending far eastward in both a northern and a southern direction, pulverulent, white, earthy gypsum covers the surface. At the wells this gypsum is from 18 to 27 feet thick. In this immediate vicinity the gypsum is impregnated with native sulphur, which will be referred to below. Outside of this gypsum area, the Toyah Basin is covered by loose detritus of igneous rock, sandstone, and limestone. This material is wash from the adjacent highlands, the igneous rock coming from the Davis Mountains to the southwest.

About 1½ miles southwest of the wells is a small area of broken gray limestone, and from 5 to 7 miles west, extending in an approximately north-south belt, are low outcrops of coarse and fine-textured sandstone with interbedded limestone, which are almost buried by the surrounding Basin deposits. These are outlying Cretaceous rocks belonging to the Washita group of the Comanche series.

The "wash" of Toyah Basin extends farther west to the range of low hills in which the Rustler formation outcrops. Westward these rocks are succeeded by the belt of bedded gypsum and finally by the sandstones and limestones of the Delaware Mountain formation. These rocks all dip low to the east, but their structure, depth and extent in the Toyah Basin are unknown because of the cover of wash and the erosion that occurred previous to the deposition of the basin deposits.

Reviewing known conditions in the area covered by the reconnaissance in 1903, the following may be noted concerning the possible abundance of petroleum. There occurs here a great mass of little disturbed sedimentary rocks, some of which are bituminous. There are beds of porous rock to serve as reservoirs. Locally the strata are gently folded, and small amounts of petroleum are widely disseminated. On the other hand, there is very little shale in this region to act as an impervious cap to prevent the escape and to aid in the accumulation of oil. However, there is considerable limestone, which sometimes is an effective barrier. Then there is no general system of folds to provide for storage and the accumulation of pools, but the beds are characteristically lenticular, and there may be lenses of porous rock saturated with oil that is preserved by contiguous impervious beds.

Besides chances for oil in the older rocks, there are possibilities, in the wide extent of the unconsolidated materials of the Toyah Basin, for a combination of favorable conditions for collecting and storing disseminated petroleum. Only the drill can determine whether oil exists here in paying quantities.

SULPHUR.

The sulphur deposits of trans-Pecos Texas are described in Bulletin

No. 2 of the University of Texas Mineral Survey, by E. M. Skeats, E. A. Smith, and W. B. Phillips but, as the edition of that Bulletin is exhausted, it is thought desirable to give here the results of notes made in the fall of 1903.

Native sulphur occurs associated with gypsum at several localities in northeastern El Paso and northern Reeves counties. Some prospecting and development work have been done and two carloads of sulphur have been shipped, but very little is yet known of the extent and value of these deposits.

The sulphur prospect nearest to a railroad occurs about 15 miles southwest of Guadalupe, on the Pecos Valley road. Another sulphur prospect, but of less value, is about the same distance northwest of Toyah, on the Texas and Pacific Railroad. Other prospects occur scattered over the gypsum belt at various distances, up to 25 miles. There would be little difficulty in constructing a railroad into the sulphur fields, for the country is open and rises gradually westward across the nearly flat Toyah Basin and through valleys in the Rustler Hills into the gypsum plain beyond.

This country is fairly well supplied with water from shallow wells, but all of it is strongly mineralized. The water averages almost 300 parts per 100,000 of dissolved salts, of which about two-thirds is calcium sulphate. Fuel can be furnished for a limited time by a growth of old stunted junipers. Moreover, there is a hope that petroleum or gas in profitable quantities will be found in this region.

The most extensive prospecting has been done in the vicinity of Maverick Spring, which is in the Toyah Basin, about 9 miles northeast of Rustler Spring, near the eastern base of the Rustler Hills. Several shallow prospect holes have been dug here and an area of considerable size has been scraped. The sulphur occurs in a bare, flat, gypsum-covered area whose surface is strewn with well-rounded quartz pebbles that average about one-half inch in diameter. The gypsum also contains quartz pebbles and bits of organic matter. The pebbles doubtless are derived from the conglomerate of the Rustler formation and the gypsum appears to have been transported from near-by outcrops of Castile gypsum.

Sulphur occurs here in different ways; sometimes it is superficially developed on the gypsum as a thin amorphous film. Again, it is rather minutely disseminated throughout the mass of gypsum. One broad strip exposes a bed of brownish earth about 3 feet thick, highly impregnated with undeterminable organic matter, having a peculiar sulphur odor and containing considerable disseminated, minute sulphur crystals. A cut in this vicinity shows about 2 feet of rather compact amorphous sulphur, which also contains small pebbles. This entire area seems to be "spotted."

This is the only locality where considerable prospecting has been done, though no sulphur has been shipped from it (Plate VI, *A*). E. M. Skeats, who is familiar with the work, reports a pit section 41 feet deep in gypsum, sand and gravel, situated about 5 miles northwest of Maverick Spring. Samples were taken every few feet, an average of which gave 26 per cent of free sulphur, though some tests went as high as 46 per cent. Mr. Skeats reports the presence of free sulphuric acid in the waters associated with the sulphur deposits, and he mentions that a 21-foot bore hole struck a mixture of gas which burned for several days. Mr. Skeats estimates that, in this Maverick Spring vicinity, there are over 300,000 tons of sulphur within 40 feet of the surface.

The most extensive development work has been done about 6 miles north of Rustler Springs (Plate VI, *B*). It is reported that three or four years ago 100 men or more were employed here for several months. A number of acres were stripped, a furnace was erected for treating the ore by the superheated steam process, and two or three carloads of refined sulphur were shipped from Guadalupe. The strippings show at the surface from 2 to 3 feet of porous, earthy gypsum, containing a few rounded pebbles of quartz, overlying the ore, which averages about 4 feet in thickness. The ore is a brownish, porous substance, containing disseminated sulphur crystals. An analysis by Mr. George Steiger, of the United States Geological Survey, shows that the bulk of the ore is silicia, with a little alumina; and that no calcium, sulphuric acid or carbon dioxide are present. This ore contains considerable organic matter of an undetermined nature, and 18.36 per cent of free sulphur.

About 10 miles northwest of Rustler Spring, just east of the Toyah-Guadalupe road, is a low gypsum hill capped by 20 feet of gray limestone lying practically flat. Several hundred feet have been stripped along the southern side of the hill, exposing a good section. Amorphous yellow sulphur occurs disseminated in irregular streaks and patches in the gypsum, occasionally rudely following the bedding and again crossing it, not following any regular course. The sulphur-impregnated zone averages about 3 feet in width. The contact between the gypsum and limestone is extremely irregular. They are intimately intermingled and porous, which suggests that the gypsum had its origin in the limestone adjacent to the contact.

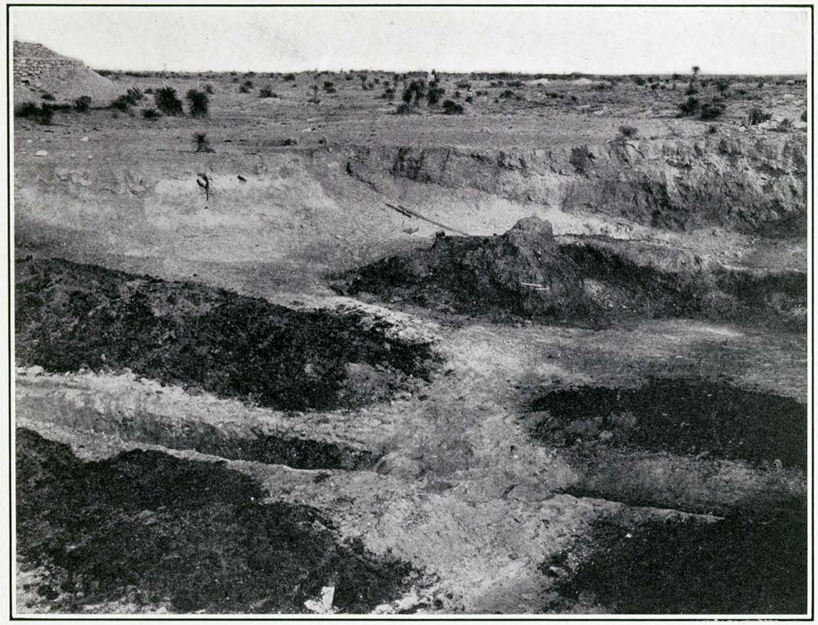
A test pit 1½ miles northeast of this locality shows 6 feet of gypsum containing disseminated sulphur underlain by 3 feet of bituminous limestone.

South of Delaware Creek, about 4 miles southeast of Delaware Spring and 18 miles northwest of Rustler Spring, is a prominent three-peaked hill of limestone underlain by gypsum. A cavern over 100 feet deep shows superficial alteration of the limestone into white, porous gypsum, with which thin coatings of native sulphur are associated. The odor of hydrogen sulphide is easily detected in the cavern, and there can be little doubt that the alteration of the limestone and the origin of the sulphur are due to that gas.

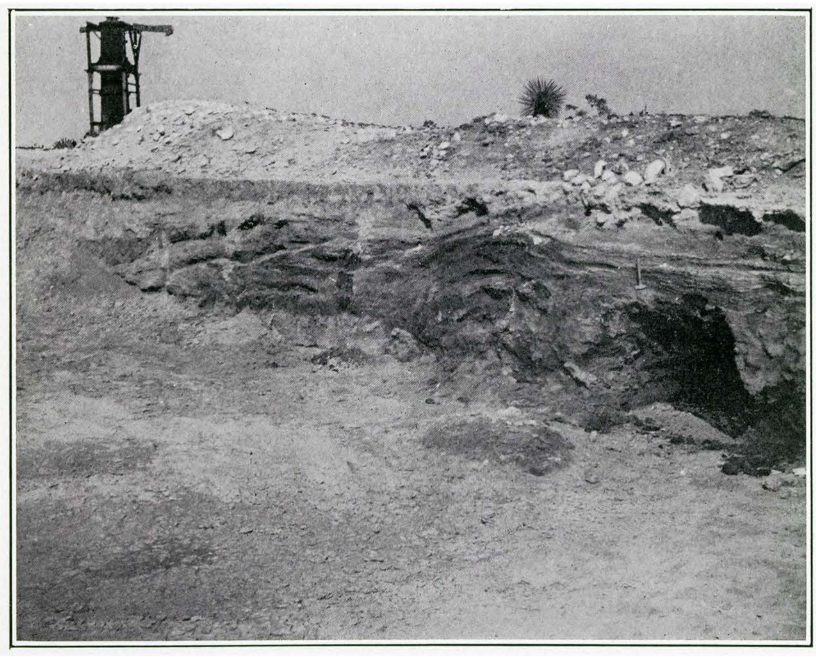
On the north side of Cottonwood Draw, about 16 miles northwest of Toyah, contiguous to the oil wells in Toyah Basin, a small area has been scraped, exposing some sulphur sparingly disseminated in the gypsum.

Sulphur also occurs in small quantities, disseminated in the gypsum, about 10 miles northwest of Rustler Springs, near Stinking Seep. A few other localities are also known where sulphur is seen at the surface associated with gypsum, but little prospecting has been done at these places.

These are practically all of the known occurrences of sulphur in this region. Sulphur is found throughout a wide area, and locally it is fairly well concentrated, but very little is known of the extent and value of



A. SULPHUR PROSPECT NEAR MAVERICK SPRING.
Photograph by W. B. Phillips.



B SULPHUR PROSPECT, 6 MILES NORTH OF RUSTLER SPRING.

these deposits. That can be determined only by persistent prospecting.

Concerning the origin of the sulphur, the most significant facts seem to be its association with gypsum and organic matter and the occurrence of hydrogen sulphide. There has been no recent volcanic activity in this region.

The association of sulphur, gypsum, and organic matter suggests their genetic relationship, inasmuch as sulphur can be formed by the reduction of gypsum. The origin of sulphur has been accounted for by considering that organic matter reduces gypsum to calcium sulphide, which, being acted on by carbonic acid waters, yields calcium carbonate and hydrogen sulphide, and, from the latter, sulphur is formed by oxidation. Gypsum, however, is a stable compound, and though it can be reduced by the application of heat, the above reactions at ordinary temperatures, except through the intervention of micro-organisms, have not been verified. Possibly such favorable conditions existed during the formation of some of the sulphur under consideration which, besides being associated with gypsum and organic matter, apparently was formed at or near the surface.

Hydrogen sulphide, though its source is not clear, is widespread throughout the area under consideration, and it is a familiar fact that native sulphur is formed by the oxidation of this gas. By such a reaction sulphur is now being deposited in Delaware Creek, where water from a sulphur spring mingles with water from Delaware Spring. A sample from the bed of the creek, collected by Captain Pope in 1854, showed 18.28 per cent of free sulphur. Again, the superficial, rust-like coating of sulphur on gypsum near Maverick Spring can be accounted for by the oxidation of hydrogen sulphide contained in water trickling over the rock. Thus throughout this region, each occurrence having its own characteristics, in the final reaction the sulphur may have been formed by the oxidation of hydrogen sulphide, but the ultimate source of this gas needs further investigation, both in the field and laboratory.

UNDERGROUND WATER.

CLIMATOLOGICAL NOTES.

Excepting the Rio Grande and the Pecos rivers, whose chief sources are far distant in the Rocky Mountains, the water supply of the area under consideration is dependent on local climatic conditions. Stations in this region where systematic weather observations have been made are few and far apart. Records have been kept at El Paso, however, since 1878. These represent the general climatical conditions in the territory under consideration, but only in a broad way, for the area is large and the different physical aspects of the country involve corresponding changes in weather. The El Paso records, supplemented by rainfall data taken at Kent, Carlsbad, and Fort Davis, are as follows:

Monthly and annual precipitation, in inches, at El Paso, Texas.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1878	....	....	....	....	....	....	1.25	2 55	0.66	1.02	0.66	0.11	....
1879	1.57	0.83	0.18	0.07	0.00	0.08	2.47	0.35	0.04	0.95	0 01	0 26	6 81
1880	1.01	T	0.30	0.10	0.00	0.00	6.54	3 60	0.80	0.47	0.02	1.53	14.37
1881	0.35	0.24	0.01	0.22	1.83	0.02	8.18	3.15	1.44	1.45	0.50	0.78	18.17
1882	0.64	0.78	0.38	0.00	0.10	0.43	1 26	2.82	0.40	0.00	1.46	0.00	8.27
1883	0.10	0.40	2.09	0.10	0.02	0.04	2 84	1.34	2 51	2.03	0.61	0.84	12.92
1884	0.55	0.84	0.33	0.91	T	0 11	0.46	3.98	3.68	5.15	0 22	2.07	18.30
1885	0.12	0 03	0.34	0.04	1.27	2.63	1.06	0.46	0 22	0.46	0 31	0.37	7.31
1886	0 31	0 44	0.28	T	0.01	1 03	1.62	1.85	1.16	0.80	0.52	0.04	8.06
1887	0.03	0.15	0.32	0.09	0.13	0 34	0.73	1 68	0.94	0.78	0.56	1.01	6.76
1888	0.32	1.51	0.95	0.74	0.15	0 42	1.39	1.32	0.49	1.13	1.32	0 05	9.79
1889	0.76	0.18	0.67	0.04	0.00	0.28	1.59	0 04	2.64	0.35	0.55	0.00	7.10
1890	0.72	0.02	0.01	0.06	T	0.63	0.95	3.25	1.81	0.41	0.35	0 28	8.49
1891	0.27	0.09	0.16	0.00	0.38	0 40	0.06	0.13	0.23	T	T	0.50	2.22
1892	1.25	0.57	0 30	0.11	T	T	1.14	0.07	0 12	0.22	0.93	0.61	5.32
1893	0.02	0.52	0.31	0 00	2.28	T	2.08	3.15	2.08	T	0.02	0 42	10 88
1894	0.33	0.29	0.13	0.01	0 01	0 01	1.40	0.64	0 40	0.39	0.00	0.63	4 24
1895	0.65	0.17	0.05	T	2.11	0.21	2.48	2.01	0.28	0 88	1.05	0.31	10.20
1896	1.63	0.14	T	T	T	0.60	2 73	1.09	1.48	2.02	0.04	0 06	9.79
1897	0 54	0.00	0.05	0.14	0 46	2.17	2.89	2.57	2.73	0 77	T	0 09	12.41
1898	0.25	0.04	0.43	0 81	0.01	0 46	1.46	1.00	0.50	T	0.16	1.04	6 16
1899	0.06	0.03	0.23	0 88	T	0 61	3.08	0.91	0.64	0 01	0 64	0.21	7.30
1900	0 11	0.43	0 26	0.02	0 41	0.27	2.38	0.43	2.18	1.23	0.23	T	7.95
1901	0.35	0.68	0.47	0.47	0.05	0.39	1.05	0.34	0 82	2.98	1.05	0.03	8.68
1902	0.57	0.01	0.00	0.00	T	0.01	3.27	2.85	1.86	0.31	0 49	0.78	10 15
1903	0.61	1.09	0.15	0.54	0.29	2.50	1.19	1.73	3.52	0.00	0.00	0.01	11.63

Mean monthly and annual precipitation, in inches, at El Paso, Kent and Fort Davis, Texas, and at Carlsbad, New Mexico.

Stations.	Jan.		Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
El Paso	0.53	0.42	0.40	0.15	0.49	0 39	2.08	1.80	1.11	0.92	0.50	0.54	9 33
Kent	0.53	0.50	0.12	0.69	0.53	2 09	2 35	1.59	1.79	1.04	0 97	0 52	12.72
Fort Davis	0.45	0.26	0.16	0.47	0.79	2.00	2.68	2.29	3.21	0 69	0.70	0 33	14 03
Carlsbad	0.28	0.23	0.29	0.36	0.65	2.56	2.86	2 42	1.09	0.89	0.41	0.44	12.48

Monthly and annual depth of evaporation, in inches, at El Paso.

[Computed from the means of tri-daily determinations of dew-point and wet-bulb observations in thermometer shelter.]

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
4.0	3.9	6.0	8.4	10.7	13.6	9.4	7.7	5.6	5.2	4.6	2.9	82.0

Mean monthly maximum temperature at El Paso.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
57°	63°	70°	79°	88°	96°	95°	93°	87°	78°	66°	59°

Mean monthly minimum temperature at El Paso.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
31	35	42	49	58	66	69	67	61	50	38	32

Mean monthly and annual temperature at El Paso.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
44.5	49.4	55.8	63.8	72.3	80.2	81.9	79.0	73.1	63.0	51.5	46.1	63.4

Monthly and annual mean relative humidity at El Paso, in per cents, for 14 years to the end of 1901.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
47.3	40.1	30.0	24.0	23.2	27.5	45.0	46.4	47.1	45.3	44.4	45.1	38.8

These tables show the arid nature of the climate of the area under consideration. At El Paso, whose elevation is 3,700 feet above the sea, the mean annual temperature is 63.4°. The monthly maximum temperature ranges from 57° in January to 96° in June, and the monthly minimum from 31° in January to 69° in July. The diurnal variation is marked, amounting to almost 30°, so that, although the days in summer are hot, the nights are cool. The atmosphere is dry, the mean annual relative humidity amounting to only 38.8 per cent. This dryness is emphasized by the rainfall tables, which show a variation in the mean annual amount, from 9.33 inches at El Paso, in the Rio Grande Valley, to 14.03 inches at Fort Davis, in the Davis Mountains. The type is peculiar. Most of the rain falls in heavy, local showers during the warmer months. At El Paso, for instance, half of the annual amount occurs during July, August, and September. This type of rainfall is fortunate. During a heavy shower the soil becomes saturated and water readily percolates downward to replenish the underground store. Moreover, abundant storm water can be collected in "tanks." Whereas, if the scanty rainfall were gentler and more evenly distributed, a much larger fraction of it would escape by evaporation than at present.

GENERAL STATEMENT.

It is well known that the ultimate source of underground water is rainfall. Part of the rainfall runs off on the surface of the ground to join the rivers; another part is returned to the atmosphere again by evaporation, while a third portion sinks through pervious materials and becomes underground water. The relative amounts of the rainfall that are thus disposed of vary greatly. In arid regions often there is no surface run-off and evaporation is considerable, while different conditions determine the ratio between the amount of rainfall that is evaporated and that which becomes underground water. Underground water has been divided into two classes: shallow underground water, commonly called ground water, and deeper underground water, for which no generally accepted term has been found.

Ground water is the water between the surface and the first impervious material that retards farther downward movement. Water percolating from the surface tends to stop on such material and to collect in the pores of the overlying deposits, which become saturated to a greater or less thickness. The upper surface of this saturated zone is called the water table. The water table is an irregular, variable surface whose position changes with several factors, chief of which are the quantity of water, the amount of evaporation, the form of the underlying impervious rock, the surface topography, and the character of the pervious material. This water is seldom stagnant, but tends to flow with extreme slowness from a higher to a lower level, the general trend being toward adjacent valleys, thus corresponding with the surface drainage.

The quantity of ground water is limited by the local rainfall, but the amount varies with other factors, generally increasing with the greater collecting area and with the depth of the surface materials. Drainage basins with large catchment areas tend to collect more ground water than smaller ones. The character of the soil and underlying materials is important, for porous substances collect more rainfall than those of finer texture. Moreover, porous deposits of considerable thickness permit the water to percolate to such depths as to escape much loss by evaporation. If relatively impervious rock is exposed at the surface, or if the depth of superficial porous deposits is inconsiderable, very little or no ground water will collect permanently, especially in a dry climate.

The quality of the ground water varies chiefly with the nature and amount of the soluble constituents in the material through which it flows. The water dissolves all the soluble matter it can, and if this be considerable or of a deleterious nature, the water is materially affected. Unless, however, there be a superabundance of soluble material the constant leaching by moving waters tends in time to improve the quality.

Ground water becomes available for use both naturally and artificially. It reaches the surface again naturally in springs and by seepage into drainage ways, and is commonly made available artificially by tapping the water table in wells. Wells that are supplied with ground water commonly are characterized by the fact that water does not rise above the horizon where first found, but stands in them at the general level of the surrounding water table. Other methods of recovering ground water, especially resorted to in arid regions, are by infiltration galleries and by subsurface dams. An infiltration gallery is a ditch or tunnel constructed across the direction of underflow at a sufficient depth to collect the ground water, and amounts practically to a series of connected wells. A subsurface dam is one extending down to the impervious rock and across the direction of the underflow which thus, in a narrow valley, can be impounded.

Deeper underground water lies beneath the impermeable rock that is nearest the ground and usually is confined by an overlying impervious stratum. Deeper underground water, unlike ground water, is little controlled by local topographic and surface conditions, but is largely dependent upon the texture and structure of the water-bearing rocks. It may have its source considerably distant from the place where found.

A portion of the underground water occurs in rock cracks and crevices and in open underground channels in soluble rocks like limestone and gypsum. These occurrences, however, are relatively of minor importance. The great mass of underground water is contained in rock pores and interstices, which exist in all rocks, even the most dense. Fine-textured compact rocks are relatively of little importance as water carriers, the chief available reservoirs being the comparatively loose-textured, more permeable rocks.

Structure is also an important factor in the occurrence of underground water, for if the rocks are much cracked and broken by joints or faults, their usefulness as water carriers is much impaired. Water passing through such rocks tends to be diverted by the joint cracks and the faults breaking the rocks into blocks interfere with their carrying capacity. Yet, under favorable conditions, water is collected by means of such disturbances into locally important supplies. In general, gently inclined, little-disturbed rocks are the most favorable for obtaining underground water.

The supply is obtained from rainwater that is absorbed at the outcrops and from streams that flow across the rocks. Additional supplies are derived underground by seepage from other occurrences of underground water.

Underground water is rarely stationary, but moves with extreme slowness, the water flowing from localities of higher to lower pressure, the chief factors in the movement being the number and size of the pores in the reservoir and the pressure gradient or change in head due chiefly to gravity. As an instance of the extreme slowness of the movement of underground water it may be mentioned that Darton estimates that the rate of flow in the Dakota sandstone does not much exceed a mile or two a year.[34]

The available deeper underground water commonly occurs in sediments which may contain several horizons of water separated by impervious beds. This water usually is under pressure, and when the porous horizon is reached in a well the water rises above the level at which it was struck to a greater or less extent. When the pressure is sufficient to cause overflow at the surface an artesian well results.[35]

Besides underground water, an important source of supply in arid regions is impounded storm water stored on the surface in "tanks." A "tank" is a storage reservoir commonly made by building a dam across a valley of favorable size and location to receive and hold the drainage.

[34]Eighteenth Annual Report, United States Geological Survey, Part IV, p. 609, 1897.

[35]The term artesian sometimes is used in a broader sense to include all under ground water that is under pressure enough to cause it to rise at all in wells; and the term "flowing" and "nonflowing" artesian wells are used to denote, respectively. whether the water is naturally discharged at the surface or whether pumping has to be resorted to.

During the occasional heavy summer showers characteristic of this region the quantity of water sometimes flowing down a valley furnishes a sufficient supply for several months or a year, if properly stored.

In the area under consideration the texture and structure of the rocks and general conditions are such that comparatively little water is found in the consolidated formations that constitute the highland masses. Instead, the chief underground water resources are found in the unconsolidated materials that occur in the valleys and basins. In these deposits both shallow and deeper underground water occurs. Tanks have also been constructed in a number of places.

UNDERGROUND WATER IN THE TOYAH BASIN.

There is a comparative abundance of water in the Toyah Basin. The Pecos River crosses the middle of this area; a number of artesian wells supply the town of Pecos; water is plentiful at Toyah, and several thousand cattle are supported by outlying wells in that part of the basin within the region under consideration.

This report is not concerned with the river waters nor with the irrigation systems connected therewith, these subjects already having been reported upon,[36] but the following facts may be reviewed. The flow of the Pecos River is shown in the following table:

PECOS RIVER MEASUREMENTS.[37]

Discharge measurement of Pecos River, Margueretta flume, and west valley ditch, near Pecos, Texas, for 1901.

Date.	Gage height.	Pecos River discharge.	Margueretta flume discharge.	West valley ditch discharge.
1901.	*Feet.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
July 5	1.2	39	155	19
July 10	.8	18	122	18
July 15	1.7	67	182	23
July 21	.7	16	127	18
August 6	5	831	143	18
August 11	2.1	95	216	19
August 16	6.6	1,350	216	19
August 23	2.9	181	155	24
September 1	2.2	108	106	17
September 16	7.9	1,940	120	11
September 24	3	184	108	9
October 3	2.25	109	107	8
October 10	2.4	128	108	7
October 16	2.4	118	106	5
October 24	3.2	273	105	8
November 4	10.3	3,120	97	9

[36] Harrington, H. H., A Preliminary Report on the Soils and Waters of the Upper Rio Grandè and Pecos valleys in Texas, Bulletin No. 2, Geological Survey of Texas, 1890.

T. H. Means and F. D. Gardner, A Soil Survey in the Pecos Valley, Report No. 64, United States Department of Agriculture, 1900.

Taylor, T. U., Irrigation Systems of Texas, Water Supply and Irrigation, Paper No. 71, United States Geologicul Survey, 1902.

[37] Water-Supply and Irrigation Paper. United States Geological Survey, No. 66, 1902, p. 77.

Daily gage height, in feet, of Pecos River near Pecos, Texas, for 1901.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.00	3.00	3.20	1.50	5.05	4.85	1.00	2.65	2.15	2.95	3.55	4.10
2	2 00	3.00	3.20	1.50	4.60	4.90	1.00	5 30	2.25	2.60	5.55	4.00
3	2 15	3 05	3.20	1.50	2.85	3.30	1.00	5 10	2.30	2.28	9.35	4.00
4	2.20	3.00	3.20	1.55	2.30	2.85	1.00	5.10	4.55	2.15	10.15	4.00
5	2.35	3.00	3.20	1.50	2.05	2.45	1.20	5.10	7.35	2.15	10.35	4.00
6	2.55	3.05	2.95	1.45	1.70	1.95	1.30	5.00	6.35	2.10	10.60	4.00
7	2.90	3.15	2.80	1.35	1.45	2.10	1.25	4.65	4.10	2.90	12.60	4.00
8	3.35	3.20	2.65	1.30	1.30	2.75	.95	4.20	3.10	2.85	11.75	4.00
9	3.30	3.20	2.60	1.25	1 50	2.75	.85	3.25	2.85	2.50	10.40	4.00
10	3.20	3.25	2.50	1.20	1.55	2.40	.80	2.55	2.75	2.40	9.20	3.60
11	3.15	3.40	2.50	1.20	1 30	2 30	.80	2.10	2.85	2.40	8.45	3.15
12	3.65	3.70	2.50	1.15	.95	2.30	.80	3.25	5.35	2.85	7.90	3.10
13	3.65	3.75	2.50	1.00	.85	2.25	.80	4.20	6.55	2.80	7.15	2.85
14	3.60	3.90	2.25	1.00	1.00	1.70	.80	5.95	7.80	3.05	6.50	2.70
15	3 30	3.80	2.15	.95	2.05	1.35	1.75	6.40	8.40	3.80	6.15	2.70
16	2.75	3.85	2.00	.75	1.75	1.15	1.15	6.55	7.90	3.50	5.35	2.70
17	2.95	3.90	1.95	.70	1.65	1.55	.95	6.70	7.15	3.20	5.30	2.70
18	2.70	3.90	1.95	.70	1.30	1.95	.95	6.75	6.25	2.95	4.90	2.70
19	2.60	3.95	1.95	.70	.95	1.70	.90	6.65	5.35	2.75	4.15	3.00
20	2.60	4.00	1.85	.70	.80	1.45	.90	7.95	4.35	2.80	4.15	2 85
21	3.15	4.00	1.80	.70	1.65	1.15	.90	5.35	4.05	2.95	4.95	2.70
22	3 20	3.10	1.75	.70	3.00	.85	.90	3 80	3 95	3.00	4.95	2.70
23	2.75	3.10	1.70	.70	2 30	.90	.85	3 05	3.70	3.25	4.90	2.55
24	2.70	2.90	1.70	.70	1.95	1.35	4.40	2.60	2.95	3.25	4.90	2.50
25	2.70	3.30	1.65	.70	1.95	1.40	6.10	2.15	2.75	3.35	4.80	2.50
26	2.85	3.50	1.60	.70	1.25	1.35	5.20	2.00	2.65	3.20	4.70	2.50
27	3.00	3.50	1 60	.70	1.05	1.10	4.45	2.00	2.55	4.05	4.65	2.50
28	3.00	3.50	1.70	.70	1.90	1.05	3.15	3.00	2.15	3.55	4.60	2.50
29	3.00	....	1.75	.65	3.55	1.30	2.95	3.00	2.70	3.20	4 55	2.50
30	3.00	....	1.70	4.00	3.10	1.10	3.05	2.75	2.00	3.15	4 30	2.50
31	3.00	....	1.65	....	4.50	....	2.15	2.30	....	3.35	....	3.95

Irrigation has been practiced for several years in the vicinity of Pecos, water being taken from the river by a dam about 9 miles above the town; a recently organized company plans to take water at a dam about 1 mile below Riverton and to irrigate a considerable portion of the eastern part of the Toyah Basin west of the Pecos River. The Pecos River water, however, contains considerable dissolved salts, and care has to be exercised in irrigation.

The following analysis of river water, from about 10 miles below Pecos, gives an idea of its general composition:[38]

Analysis of Pecos River water.

(Samples taken November, 1894.)

	Parts per 100,000
Silica, alumina and iron	1.20
Lime	61.26
Magnesia	27.81
Soda	76.97
Potash	4.26
Sulphur trioxide	116.74
Chlorine	94.41
Carbon dioxide	6.15

[38]Bulletin No. 34, New Mexico Coll. of Agric., p. 72, 1900.

Crystal water and organic matter	27.54
	416.34
Oxygen equivalent of chlorine	21.34
Total solids	395.00

Practically no attention has been given to developing the underflow of the Pecos River by pumping, as is done in the Rio Grande Valley. This underflow probably will not be much used until the supply of surface water materially decreases incident to increased irrigation up the valley. Yet it is likely that a profitable field for exploitation exists here.

Disregarding the river, the main water supply of the Toyah Basin is contained in the unconsolidated deposits that underlie it to a considerable but unknown depth. The most conspicuous occurrence of underground water in the Toyah Basin is the artesian supply at Pecos. In this vicinity flowing wells are reported from about 3 miles north of Pecos, 2 miles west and 6 miles south.*

The following partial list prepared by Mr. Willard H. Denis illustrates general conditions:

Partial list of artesian wells in the vicinity of Pecos.

Name of Owner.	Location.	Depth to artesian water horizon.
T. & P. Ry	Pecos	214
P. V. & N. E. Ry	Pecos	226
Joe Kraus	Pecos	215
Ben. Krause	Pecos	220
City Well	Pecos	235
W. H. Drummond	Pecos	235
E. Meyenburg	Pecos	240
T. B. Pruett	Pecos	255
W. L. Ross	Pecos	265
Mrs. C. F. Thomason	Pecos	266
Ed. Vickers	Pecos	280
W. M. McKemey	Pecos	284
Mrs. White	½ m. west of Pecos	260
Mrs. Gessler	½ m. west of Pecos	265
——— Powers	1 m. west of Pecos	165
C. H. Merriman	1 m. west of Pecos	165
Jas. E. Bowen	½ m. north of Pecos	160
R. N. Couch	3 m. north of Pecos	90
Chas. Schilling	2 m. northwest of Pecos	90
Mrs. M. Mitchell	2 m. northwest of Pecos	93
Mrs. M. Mitchell	2 m. northwest of Pecos	96
Bowen, Joyce & Co.	6 m. southeast of Pecos	282

No complete record of a Pecos well was obtained. A feeble first flow

* There is a fair artesian well 194 feet deep 8 miles north of Fort Stockton, Pecos county, 6 inches in diameter.

of strongly saline water is reported at a depth of about 100 feet below which clay generally is found down to the main flow which occurs in gravel.

One of the early artesian wells in Pecos was drilled in 1886 by the Texas and Pacific Railway Company. This well is of 4-inch bore. It is 214 feet deep, and the water rises in a pipe 28 feet above the surface. A capacity of 85,000 gallons a day is reported and no diminution in the supply has been noticed.

It will be seen from the list of wells that the depth to artesian water increases from the north and west toward Pecos, indicating that the water-bearing horizon dips southeastward. The well 6 miles southeast of Pecos in which the water rose to the surface only, suggests that this point is the southward limit of the occurrence of artesian water, but the test can not be considered final. No artesian water has been found in the Toyah Basin east of the river. It is generally believed that the northern and western boundaries of the area of flowing wells are approximately known and that the southward limit remains to be found.

The quality of the Pecos artesian water is shown by the following analysis of a sample collected from the Pecos Valley Railroad stock yard well in August, 1902:[39]

Analysis of water at Pecos.[40]

	Grains per gallon.
Silica	1.5
Sulphate of lime	16.6
Carbonate of lime	31.2
Carbonate of magnesia	6.9
Organic matter	13.8
Chloride of sodium	60.2
Sulphate of magnesia	14.9
Total solids	145.1

At Toyah there is a flowing artesian well that was put down by the Texas and Pacific Railway in 1882. The depth of the well is 832 feet, but very little is known of what was encountered in the drilling. It is reported that the drill went through 800 feet of "bowlders, etc.," and a 32-foot bed of "concrete," and reached white sand at the bottom. These statements imply that bed rock was not encountered. The horizon at which the flow of water was obtained apparently is not known. Another well near by, reported to have been sunk 514 feet, yielded a flow of 9 gallons a minute. Water flows from the deeper well at the rate of 300 gallons a minute, as reported by the railroad company; and Mr. A. M. Levinson, road master, in 1903 obtained a pressure of 45 pounds when the well was tested by a steam gauge. The water contains abundant hydrogen sul-

[39]Furnished by Mr. Avery Turner.

[40]Note.—The water analyses given in this report have been gathered from many sources, and are not uniform in expression. They are reproduced as received, for reduction to a common standard in most cases is impossible. To convert parts per 100,000 to grains per U. S. gallon multiply by 0.583.

phide and 121.5 grains of solid matter per gallon, according to the railroad company. A complete analysis was not made, but the following substances are reported to be present in the order of their quantity: Sulphate of lime, carbonate of lime, carbonate of magnesium and chloride of sodium. The water is not used for steaming purposes, the railroad company having a large tank at Toyah in which storm water is collected.

Apparently there is no connection between the Toyah artesian water and that at Pecos. These are the only flowing wells in the entire area covered by this report. Water under some pressure, however, has been reported in a few other localities in the Toyah Basin.

In the Joe White well, about 27 miles northwest of Pecos, which is 315 feet deep, the main water horizon occurs at a depth of 260 feet and the water rises 68 feet.

The "Big Phillip" well, 10 miles east of White's and about 200 feet lower, is 395 feet deep, and water reported to rise 75 feet was struck at a depth of 275 feet. If the water in these two wells comes from the same bed, an eastward dip is here indicated.

At the Hurd well, 7 miles northwest of Pecos, water is said to occur within 20 feet of the surface. The depth of the well is 400 feet, but the horizon at which water was found is not reported. However, in the Casey wells, 7 or 8 miles west of the Hurd well, one of which is 207 feet deep, the water is reported not to rise. The quantity of water supplied by these wells has not been measured, but it is sufficient for stock purposes.

There is not enough information to correlate these different occurrences of deeper seated water. It is evident, however, that there is a considerable quantity under pressure in the unconsolidated deposits of the Toyah Basin and that water is likely to be found at depths approximating those of the wells named. Occasionally, though, quicksand may give trouble, as was the case with an abandoned well about 4 miles east of Joe White's.

Besides these deeper wells, which strike water generally under pressure, and whose topographic location has little relation to its occurrence, there are a number of successful shallow wells in the Toyah Basin. The shallow wells are commonly situated in or near the beds of arroyos where surface drainage supplies the underlying porous material with storm water.

Conditions vary in different valleys. In the Incline, one of the heads of Salt Draw, southwest of Guadalupe, several wells strike water at depths between 8 and 25 feet from the surface. In Fourmile Draw there are two wells near the surface, one near the head contains excessively saline water, and one near the mouth, which will be referred to again, furnishes fresh water. In the draw immediately north of Toyah the depth to water is 20 feet. In San Martine Draw water is found at 36 and 60 feet, and in the "draw" southwest of Toyah it occurs at about 90 feet.

The town of Toyah is supplied by a number of wells that average only 25 feet in depth. A typical section is given as follows: Soil, 10 feet; yellow clay, 10 feet; water-bearing gravel, 5 feet, yellow clay. Though occurring under a cap of clay, the water is reported to be under no appreciable pressure, and it is commonly brought to the surface by windmills. Ample water is available, but it is strongly impregnated with gypsum and other salts. For drinking purposes the people generally use water that is hauled by the railroad from Monahans, about 40 miles east of Pecos.

Practically all of the water in the Toyah Basin carries abundant dissolved salts, largely calcium sulphate, which is derived, no doubt, from widely disseminated gypsum among the basin deposits. Locally excessively saline water occurs. For instance, Dr. Phillips, in February, 1904, collected two samples from "draws" in the vicinity of Maverick Spring, which show large quantities of sodium chloride, according to the following analysis by Mr. S. H. Worrell, but these waters are exceptional:

Analysis of water from near Maverick Spring.

From Salt Draw north of house at Maverick Spring.	Parts per 100,000.	From Salt Draw west of house at Maverick Spring.	Parts per 100,000.
Silica	0.08	Silica	4.64
Alumina	1.44	Alumina	2.48
Iron salts	trace.	Iron salts	trace
Sodium carbonate	126.56	Sodium carbonate	216.97
Sodium chloride	1761.89	Sodium chloride	2245.32
Magnesium chloride	72.26	Magnesium chloride	55.71
Magnesium sulphate	123.72	Magnesium sulphate	213.96
Calcium sulphate	470.13	Calcium sulphate	401.72
Potash	none.	Potash	none.
Total solids	2562.08	Total solids	3140.80

Much free hydrogen sulphide is present.

An interesting occurrence of soft water in the Toyah Basin is at Tucker's well, about 2½ miles northwest of Riverton. This well is a small one, in which water collects in a barrel sunk in the bed of Fourmile Draw. An area of sandstone of Washita age is near by, and for a considerable distance the valley is strewn with sand, and no gypsum was seen. The freshness of the water is due to the absence of salts in the immediate vicinity of the accumulating area. The following analysis is furnished by Mr. Avery Turner:

Analysis of water at Tucker's well.

	Grains per gallon.
Silica	1.8
Iron and alumina	.1
Carbonate of lime	8.5
Carbonate of magnesia	11.5
Chloride of lime	.4
Sulphate of magnesia	1.7
Chloride of sodium	1.5

Sulphate of sodium	2.3
Organic matter	4.0
Total solids	31.8

Just off the western margin of the basin in the upper valley of San Martine Draw there are other occurrences of fresh water. Several springs occur about the base of the Davis Mountains in Jeff Davis county just south of the railroad. Some of these flow into San Martine Draw and sink into the sand and gravel which are tapped lower down near the railway and from which good fresh water is obtained at a depth of from 25 to 50 feet. The water is here fresh, because it does not pass though and dissolve deleterious salts in the upper part of its course, but farther down the valley where tapped by wells west of Toyah the water has become saline.

At one time the Texas and Pacific Railway Company is said to have considered constructing a subsurface dam in the valley of this draw just west of the San Martine section house. This project involved the construction of a cement dam on bed rock for a distance of possibly half a mile. A body of fresh water would thus be impounded, but the project was abandoned.

Besides the wells there are several springs in the Toyah Basin and adjacent to its margins. In Screwbean and Maverick springs on the eastern slope of the Rustler Hills small but persistent quantities of underground water come to the surface in gypsum and collect in pools for a short distance below the springs. These springs supply a number of cattle and are wellknown watering places for travelers. The water is highly charged with salts, especially calcium sulphate, as shown by the following analysis by Mr. S. H. Worrell:

Analysis of water from Screwbean spring.

	Parts per 100,000.
Silica	1.44
Alumina	.44
Oxide of iron	trace.
Calcium sulphate	198.62
Magnesium sulphate	63.96
Magnesium chloride	16.78
Sodium chloride	2.40
Sodium carbonate	28.72
Total solids	312.36

Farther south Burnt Spring and Twin Spring are feeble seeps occurring in gypsum. The occurrence at Burnt Spring is interesting because globules of oil are occasionally found in the water. Petrican Spring, about 9 miles northwest of Toyah, is a strong body of water that issues from the contact of loose gypsum on a compact quartz gravel with calcareous cement. The water is successfully used for irrigating several acres of truck garden.

Toward the western margin of the Toyah Basin a number of unsuccessful wells have been sunk through the edge of the unconsolidated deposits for a short distance into bed rock. Thus, on the eastern side of the Rustler Hills southwest of Maverick Spring, two dry wells were sunk 113 and 120 feet into rock; while farther south just west of the Toyah Basin in the vicinity of Boracho and Kent five unsuccessful wells, ranging from 100 to 515 feet in depth, have been sunk.

The eastward dip of the rocks in the Guadalupe-Delaware Mountains suggests that artesian water may be obtained from the bed rock in the Toyah Basin. Capt. John Pope in 1855-57, was thus led to make his artesian well experiment about 10 miles east of Delaware Creek. Shumard[41] did not favor the project, but Pope went ahead and under great difficulties sank two wells. The deepest of these reached 1050 feet; both were failures. From fragmentary reports it appears that water which rose 70 feet was found at 365 feet from the surface, and a second supply which rose 390 feet was struck at 640 feet. Much of the drilling was done in "soft variegated marls and clays," which caused no end of trouble.[42]

The occurrence of artesian water is well known to depend on a number of favorable conditions which have been summarized by Chamberlin as follows:

1. A pervious stratum to permit the entrance and the passage of the water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent escape upward.
4. An inclination of these beds so that the edge at which the waters enter will be higher than the surface of the well.
5. A suitable exposure of the edge of the porous stratum so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface of the well.[43]

In the area under consideration several of these conditions are present, but there are unfavorable complications. The Delaware Mountain formation in the northern part of the area contains pervious sandstone members overlain and underlain by relatively impervious limestone and the dip of the rocks is eastward toward the Pecos. But so far as known the sandstone members are not very persistent; it having been observed along the scarp of the Delaware Mountains that a locally well-developed bed of sandstone often merges into shale or limestone. The rainfall is slight, and there is no chance for considerable quantities of water to be imbibed by the sandstones, so that if artesian water were obtained from this source its amount would not be considerable. Moreover, farther

[41] G. G. Shumard, Artesian Water on the Llano Estacado, Bulletin 1, Geological Survey of Texas.

[42] Annual Report of Capt. A. A. Humphreys to the Secretary of War, Dec., 1858.

[43] Chamberlin, T. C., Fifth Annual Report United States Geological Survey, 1885, pp. 131-173.

south there are few pervious beds in the Delaware Mountain formation, but the prevailing rock is dense nonmagnesian limestone. Besides these unfavorable aspects of the requisites for the presence of artesian waters, two other unfavorable conditions are the disturbed belt which extends south from the mouth of Delaware Creek and the erosion which has occurred in the Pecos Valley. The faulting and folding in the disturbed belt have modified the prevailing eastward dip and thus interfered with one of the requisite conditions. The amount of erosion in the Pecos Valley previous to the deposition of the unconsolidated deposits of the Toyah Basin is unknown, but it may have persisted so far as to have removed the cover and a considerable part of the Delaware Mountain formation. In the area under consideration, therefore, so far as known, the outlook is not very favorable for the occurrence of artesian water in bed rock beneath the basin deposits.

UNDERGROUND WATER IN THE GYPSUM PLAIN.

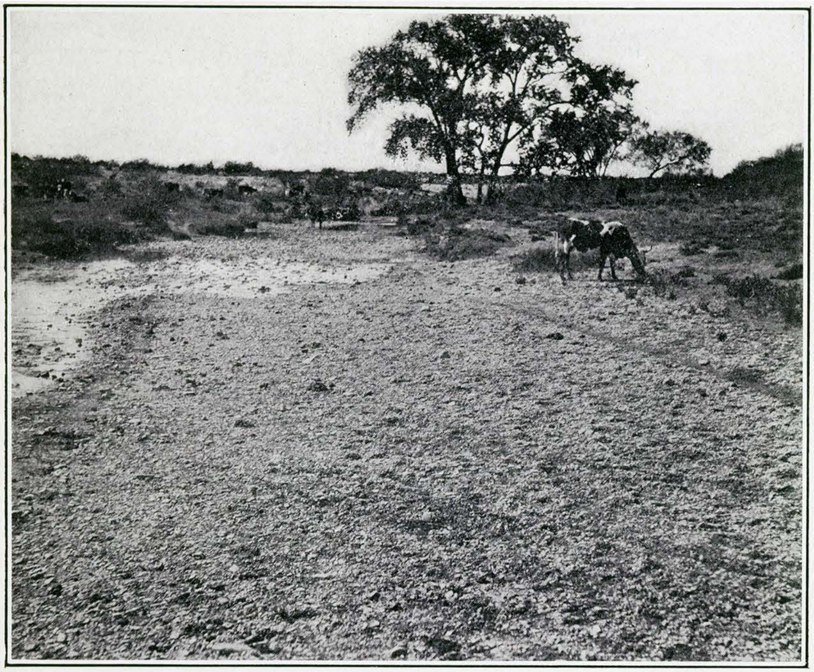
In the plain west of the Rustler Hills peculiar underground water conditions prevail consequent upon the nature of the underlying Castile gypsum. It will be recalled that this area is occupied by massive white gypsum containing intercalated thin bands of limestone, and that the gypsum is cavernous and jointed. The surface of the gypsum is commonly earthy and pulverulent, and the valleys contain débris brought from the hills to the west. This gypsum belt is fairly well supplied with water, which, as would be expected, contains considerable calcium sulphate in solution; but the occurrence of the water is irregular.

Delaware Creek crosses the northern end of the gypsum belt. It is fed by springs along its course, and, besides the Pecos River, is the only perennially flowing stream in the entire area under consideration. The creek flows through the broad gypsum plain and in a narrow gorge-like channel averaging about 30 feet deep, and access to the water is difficult. There are several crossings, however, and the water flows in a clear but saline stream. A sample collected by Captain Pope 30 miles below Delaware Spring was found to contain 187 grains of dissolved salts per gallon by J. C. Booth.[44] In September, 1898, Mr. T. U. Taylor measured a flow of 4 second feet at the crossing of the Pecos Valley Railroad, when the water was said to be at a low stage.

In the bed of Cottonwood Draw, which crosses the southern part of the gypsum area, a series of springs extends for several miles below Sayles' ranch. As in the case of the springs of Delaware Creek, these springs are occasioned by erosion having tapped lines of flow of underground water. In Cottonwood Draw the water does not ordinarily run, but collects in pools (Plate VII, *A*).

A number of springs occur in the gypsum belt, the most important

[44] Exploration for a railroad route from the Mississippi River to the Pacific Ocean, Vol. II, 1855, Appendix C, p. 97.



A. SPRINGS IN COTTONWOOD DRAW 30 MILES NORTH OF KENT.

B. STINKING SEEP IN THE CASTILE GYPSUM, 10 MILES SOUTH OF DELAWARE CREEK.
Photograph by W. B. Phillips.

being: Willow, Castile, Kimble, Stinking Seep, Horseshoe and Rustler, which are located on the map.

These springs commonly occupy local depressions in which underground water percolating through the gypsum finds it easier to issue at the surface than to continue in an underground course. Several thousand cattle are supplied by these springs, though the water in all contains abundant calcium sulphate. Stinking Seep, situated about 3 miles northwest of Cooksey's ranch, has the reputation of being poisonous, which is supported by the presence of carcasses of cattle in the vicinity of the spring (Plate VII, *B*). An analysis of this water by Mr. S. H. Worrell gave:

Analysis of water from Stinking Seep.[45]

	Parts per 100,000.
Silica	2.72
Alumina and iron	trace.
Calcium sulphate	191.75
Calcium chloride	53.86
Magnesium chloride	14.30
Sodium chloride	34.93
Calcium sulphide	16.04
Total solids	313.60

Much hydrogen sulphide is also present.

The porous, cracked and cavernous condition of the gypsum causes the occurrence of water in this area, outside of the "draws," to be very uncertain, for the little water that exists in the gypsum tends to escape through these openings. A number of unsuccessful wells have been sunk, but there are also profitable ones. Local supplies have been found on the thin beds of limestone that occur in the gypsum. Such occurrences are sporadic, and their location can not be predicted. Other wells have struck local accumulations of water in caverns, as at the Cave well, about 10 miles northwest of Sayles' ranch. This well is an opening in the gypsum about 35 feet in diameter at the surface, and the water occurs 38 feet below and is 40 feet deep. This water, like much in the gypsum belt, contains hydrogen sulphide. Other such occurrences are likely to be found, but their position can not be foretold.

In the "draws" that traverse the gypsum belt more normal conditions occur, namely: in those valleys which are well filled with porous débris resting on impervious material, small amounts of shallow water are locally found. Successful wells of this type have been sunk in the beds of "draws" that extend northeast of Lone Man Mountain and in the "draw" west of Rustler Spring. Such water commonly is found from 25 to 60 feet below the surface.

The composition of the water in the gypsum belt is illustrated by the following analysis by Mr. S. H. Worrell:

[45]Collected by Dr. Wm. B. Phillips, Feb., 1904.

Analysis of water from the Gypsum belt.

	Water from well on Sayles' ranch. Parts per 100,000.	Water from well on Cooksey's ranch. Parts per 100,000.
Silica	3.16	3.44
Alumina and iron	trace.	trace.
Calcium sulphate	154.18	218.26
Calcium carbonate	45.96	......
Magnesium sulphate	trace.	11.25
Sodium carbonate	24.38	4.83
Sodium chloride	23.10	23.10
Potash	......	none.
Hydrogen sulphide	Considerable.	......
Total solids	250.78	260.88

The deepest well reported from the gypsum area was sunk 300 feet at the sulphur prospect 6 miles north of Rustler Spring. It was a dry hole, and it is not known whether the entire thickness of the gypsum was pierced. It is to be expected, however, that in the northern part of the belt good soft water under some pressure locally can be obtained from sandstone in the Delaware Mountain formation that lies below the Castile gypsum. Such water would be similar to that at D. F. White's ranch on Chico Draw (page 88). Its amount would be limited, but the quality probably would be good. There is a chance, however, that even this deep water may be of poor quality, too, for the sulphur spring on Delaware Creek (page 87) issues from sandstone in the Delaware Mountain formation. The depth at which the water may occur may be several hundred feet below the base of the gypsum. Its occurrence moreover can not be definitely predicted. In the southern part of the gypsum belt the probabilities for deep-seated water are not so promising, because the sandstones which carry the water farther north are there absent.

UNDERGROUND WATER IN THE GUADALUPE-DELAWARE MOUNTAINS.

The water supply of the eastern slope of the Guadalupe-Delaware Mountains varies with the different geologic conditions. In the unconsolidated débris east of the Guadalupe Mountains are a number of springs and shallow wells. Farther south these do not occur, but there are a few wells that obtain deep-seated water under pressure from the sandstone members of the Delaware Mountain formation. In the southern part of the mountains where there is but a thin covering of detrital material and the rocks are chiefly non-magnesian limestone neither springs nor wells furnish water, and the supply is obtained from tanks in which storm waters are collected.

Pine, Independence, Grapevine, Rector and Delaware springs are outcrops of ground water supplied by the relatively abundant rainfall and run-off of the Guadalupe Mountains. This water finds an excellent reservoir and passageway in the extensive deposits of unconsolidated débris that cover a wide extent of country at the base of the mountains.

Pine Spring is one of several situated in ravines at the base of the Guadalupe Mountains.

Independence Spring is about 5 miles southeast of Pine Spring in one of the head valleys of Delaware Creek. Water trickles from the gravel cap over ledges of sandstone in a ravine and collects in several pools before it finally disappears beneath the surface.

Grapevine, sometimes called Geyser Spring, is situated near the Texas-New Mexico boundary at the head of Black River about 15 miles east of the summit of the Guadalupe Mountains. Whether it is in New Mexico or Texas is in doubt. A strong body of water bubbles from the gravel cap and is used for irrigating a number of acres in the valley below the spring.

South Rector Spring, about 5 miles south of Grapevine Spring, is in the valley of a "draw" in which sandstone and limestone of the Delaware Mountain formation outcrop. These rocks are capped by the prevailing gravels. The water from the spring does not come directly from the gravel, but oozes from joints in the bedding planes of the rocks. The spring is a feeble one compared with Grapevine, and water collects in shallow pools on bed rock. North Rector is a similar spring about half a mile north of South Rector.

Delaware Springs are at the head of flowing water in Delaware Creek. Here water issues along the north side of the creek at the contact of gravel and a sandstone member of the Delaware Mountain formation.

The quality of the water from all of the above springs is good and the water is soft. J. C. Booth found only 60 grains of dissolved salts per gallon in a sample from Delaware Springs collected by Captain Pope. But besides this good water several saline springs issue from the bed of Delaware Creek in close proximity to the springs just mentioned having an altogether different and a deeper-seated source. The water in them bubbles up through joints in the Delaware Mountain formation that outcrops in the bed of the creek. This water contains considerable hydrogen sulphide, from which finely divided white sulphur is precipitated on contact with air. The water from one of these saline springs is reported to be poisonous. A sample analyzed by Mr. S. H. Worrell shows the following composition:

Partial analysis of water from spring at the head of Delaware Creek.

	Grains per U. S. gallon.	Parts per 100,000.
Total solids	184.53	316.86
Silica	0.28	0.48
Alumina and iron	0.32	0.56
Calcium oxide	6.64	11.40
Magnesium	5.89	10.11
Sulphur trioxide	2.46	4.22

The sample was insufficient to determine the other constituents, which are sodium, chlorine, sulphur and carbonic acid. The water is reported to contain sulphides.

A few shallow wells have been successfully sunk in the area east of the Guadalupe Mountains. Thus at Huling's ranch, in a valley above Delaware Springs, water is found in gravel at a depth of 9 feet. West of Grapevine Spring an abundance of water is found in sand and gravel in an 80-foot well in which the water is said to rise 25 feet; several similar wells are reported at the head of Black River near the State line.

South of Delaware Creek along the eastern slope of the mountains water is less plentiful. There are few if any springs, and only one successful shallow well was seen. This is on the ranch of J. G. Ussery near the head of Chico Draw where a shallow well in the bottom of the draw furnishes water for about 1000 cattle. There are several natural water holes in the upper part of this draw, however, where storm water collects on bed rock.

The successful wells in this region obtain water under pressure in sandstone members of the Delaware formation. One of these wells belongs to D. F. White on Chico Draw. The well is 546 feet deep, a partial log of which follows:

Partial log of D. F. White's well on Chico Draw.

	Thickness, feet.	Depth, feet.
Surface	13	13
Sandstone	45	58
Limestone	154	212
Sandstone	20	232
Limestone	60	292

Below the strata mentioned are alternating sandstones and limestones whose thicknesses were not reported. The first water was found in sandstone 212 feet beneath the surface below which are six other water-bearing beds. The quantity, however, was small, and the well was "shot" at the first water horizon with the effect of improving the supply. The water stands at from 80 to 100 feet below the surface. The capacity of this well is reported to be 7 gallons a minute.

Another well of this type is about 5 miles south of Independence Spring. This well is only 80 feet deep, and the water occurs at 76 feet in sandstone resting on limestone. The water rises 25 feet in such quantity that a 16-foot windmill can not pump the well dry. About 2000 cattle are reported to obtain water from this well.

It is to be expected that similar wells will be found in this vicinity. Localities should be sought which are to the east of considerable outcrops of sandstone that is underlain by limestone. Uncertainty, however, is increased by the fact that the rocks are considerably jointed. Several unsuccessful attempts have been made to obtain water—for instance a 400 foot well was sunk about 8 miles west of White's ranch and four or five shallower wells have penetrated sandstone southwest of Huling's ranch.

In the southern Delaware Mountains where very little sandstone occurs no successful wells have been sunk though several attempts have been made. Thus J. D. Aden in 1902 put down a deep well about 9 miles southwest of Sayles' ranch. This well was sunk 916 feet almost the entire way being through blue limestone belonging to the Delaware Mountain formation, with the exception of an 8-foot bed of sandstone at a depth of about 700 feet. Little or no water should be expected from this compact nonmagnesian limestone except that which may occur in local cracks and caverns. The best chance for water in this vicinity seems to be in the construction of tanks.

UNDERGROUND WATER IN THE SALT BASIN.

The Salt Basin, it has been stated, is an inclosed basin with no outlet. It receives the drainage of a large area bounded by the Sacramento Mountains on the north, by the Guadalupe, Delaware and Davis mountains on the east, and by the Sierra Vieja, Eagle, Diablo, Hueco and Cornudas mountains on the west. The basin is occupied by unconsclidated clay, sand, gravel and more or less gypsum to a considerable but unknown depth. The water supply of the Salt Basin is plentiful, but the quality generally is poor. Both ground water and deeper underground water are found in the Salt Basin, though commonly only the shallow water is utilized.

The position of the water table varies considerably. Toward the center of the basin, ground water is commonly reached at a depth of from 3 to 10 feet and locally, in the Salt Lake, for instance, water lies at a few inches below the surface. Northward and southward the position of the water table lies at a greater depth. Thus, in the wells adjacent to the State line, water is found from 25 to 35 feet below the ground. Approaching the railroad from the lowest part of the basin, different wells reach water at 16, 40, 125, 169, 265, and, at Wild Horse, at 343 feet below the surface.

Though few measurements have been made of the capacity of the wells, the quantity of water in the Salt Basin evidently is abundant. The grass is not especially good here, consisting largely of salt grass (*Sporobolus arioides*), but because of the abundant supply of water, a number of ranches are scattered over the basin. Gasoline engines are not used by the ranchmen, but often two wells supplied with windmills are situated together and, by the use of both, tanks are kept supplied with sufficient water for a large number of cattle. But one measurement of the quantity of water has been recorded in this area and that is of the railroad well at Wild Horse, which furnishes 40,000 gallons per day.

This Salt Basin water varies in quality but it is all rather strongly saline and generally gypseous. A partial test of the Wild Horse water shows the presence of 90½ grains of solid matter per gallon, the chief constituents in the order of their presence being sodium chloride, calcium carbonate and calcium sulphate. An analysis of the exceptionally strong brine of the water beneath the Salt Lake has already been given. Ranchmen report the water of some wells to be much more gypseous than that of others. The water of Crow Spring, which is an example of ground water oozing to the surface in a low hollow, is typical of the better type of water in the Salt Basin. The following is an analysis of this water, by Mr. S. H. Worrell:

Analysis of water from Crow Spring.

	Parts per 100,000.
Organic matter	34.96
Mineral matter	138.32
Total solids	173.28

ANALYSIS OF RESIDUE.

Silica	2.48
Alumina	2.28
Iron	trace.
Calcium	18.46
Magnesium	10.43
Sodium	9.72
Potassium	none.
Chlorine	13.48
Carbonic acid	12.64
Sulphuric acid	68.51

Only one well in the Salt Basin has been reported to have gone deep enough to reach a second and third horizon of underground water; namely, the well about 4 miles southeast of the Figure 2 ranch headquarters, where water was found at depths of 60, 125 and 225 feet. The quality of the underlying water, however, is not known, nor is it reported how high the water from the lower horizons rose in the well. No satisfactory logs of wells in the Salt Basin have been kept, and very little is known of the nature and variations of the underlying deposits. There is a possibility that the gypsum, salt, etc., which are chiefly responsible for the saline quality of the water, are confined to the surface deposits, so that deep wells, in which top waters are cased off, may find a better quality of water. Then, too, there is a possibility of finding deep-seated water under pressure, which should be expected if the deposits, instead of lying horizontally, are tilted so as to give a head to the underground water.

The west-dipping sandstones of the Delaware Mountain formation imbibe water from the scanty rainfall and tend to carry it beneath the basin, but how much and how far are not known. A few wells have been sunk into these sandstones, and some water was found in them northeast of the "Figure 2" ranch headquarters, as shown in the table. Some of these have gone to a depth of 300 feet and found water at 200 feet, but it is not reported that the water rose or that it is of good quality. It is to be expected that if the surface waters were excluded water from the sandstone would be comparatively fresh and under some pressure.

A few failures have been reported in wells put into the rocks along the eastern margin of the basin. Thus, a well 245 feet deep about 7 miles east of the "Figure 2" ranch was sunk in a sandstone without finding water; this may be due to the well not being deep enough. Also two unsuccessful wells, 160 feet deep, have been sunk about 15 miles southeast of the "Figure 2" ranch. A little ground water is reported from these at the contact of the unconsolidated material and limestone (?), but, after reaching the limestone, there was little chance of finding water. At Plateau and a few miles northeast of the station unsuccessful deep wells have been bored. At Plateau the railroad company sank a hole 547 feet, and nearby prospects went to a depth of 137 and 600 feet. These attempts were at the margin of the Salt Basin where conditions were unfavorable. At Plateau, the structure is concealed, yet it is probable that a zone of disturbance is in this vicinity, being in line with the western face of the Delaware Mountains.

Also unsuccessful wells have been put down along the southwestern border of the Salt Basin. West of Baylor Mountain, two dry holes about 160 feet deep were sunk, apparently into the pre-Cambrian fine-textured red sandstone. The catchment area here is small, the rocks have been disturbed, and the probabilities for finding deep-seated waters are not good.

At Van Horn, however, four successful wells have been sunk, though the horizon at which the water occurs is not known. It may come from the Van Horn sandstone, which outcrops in the valley to the northwest, or it may occur in unconsolidated material lying above the sandstone. These wells rank among the best of all in the entire area covered by this report. They are 600 feet deep and were drilled by the Texas and Pacific Railroad Company in 1886. These four wells are close together by the railroad and furnish all the water that is needed, both by the railroad and the town. The company reports the quantity unlimited. Besides occurring in such abundance, this Van Horn water is of excellent quality. A complete analysis has not been made of it, but the railroad company reports that the total solids amount to only 25½ grains per gallon, and that the chief solid constituents are calcium sulphate, sodium chloride and calcium carbonate in the order named.

Besides these wells in the Salt Basin there are several springs of fresh water along its margins. Guadalupe and Bone springs are feeble occurrences of fresh water that issues from joints in the sandstone of the Delaware Mountain formation at the southern end of the Guadalupe Mountains. Apache Spring occurs on the northeastern face of the Diablo Mountains, where the water issues from a gravel talus, the source being concealed. Yellow Spring is one of several small ones along the southeastern face of the Diablo Mountains. The water from Yellow Spring is said to come from the pre-Cambrian fine-textured red sandstone and to be sufficient to supply about 15 head of stock. Carrizo Spring is another small occurrence of ground water of good quality, coming naturally to the surface. The spring is in pre-Cambrian limestone conglomerate near the contact with the Van Horn sandstone about 7 miles northwest of Van Horn, and furnishes water enough for about 250 cattle.

Several unsuccessful attempts have been made by the railroad company to get water along the margins of Eagle Flat; namely, at Allamoore, Eagle Flat Station and at Sierra Blanca. At Allamoore the well is 300 feet deep, but it is so near bed rock of unfavorable nature and structure—flat limestone of the Hueco formation and disturbed pre-Cambrian rocks—that there was little chance for finding much water. Similar conditions prevail at Eagle Flat, where the well is 600 feet deep. At Sierra Blanca both of the railroad companies have sunk deep wells. That of the Texas and Pacific is 927 feet deep and it is reported that the well went through 20 feet of surface material, 120 feet of sand and gravel and 887 feet of loose rock. The Southern Pacific well is about 1350 feet deep. It is reported that water was struck at 980 feet, and rose 80 feet in the well; the quality, however, was not fit for engine use, and the well was abandoned. The Southern Pacific Company hauls water to Sierra Blanca and stores it in a large cistern.

A better quality of water was obtained in a well drilled by the Southern Pacific Company at Torbert, near the center of the Eagle Flat Basin, about 18 miles southeast of Sierra Blanca. This well is about 1165 feet deep, all the way in unconsolidated materials, and the water level is said to stand at 723 feet, but the water occurs in quicksand, which caused so much trouble that the well was finally abandoned.

Eagle Flat, thus far, has not furnished much water, yet a few small wells are in successful operation. The Texas and Pacific Company has a shallow well about 2 miles west of Allamoore, 187 feet deep, which is reported to furnish a small quantity of good water, and a ranchman has two wells south of the railroad, 1½ and 3 miles west of Allamoore. These are about 200 feet deep, and each is reported to furnish 4000 gallons of good water a day.

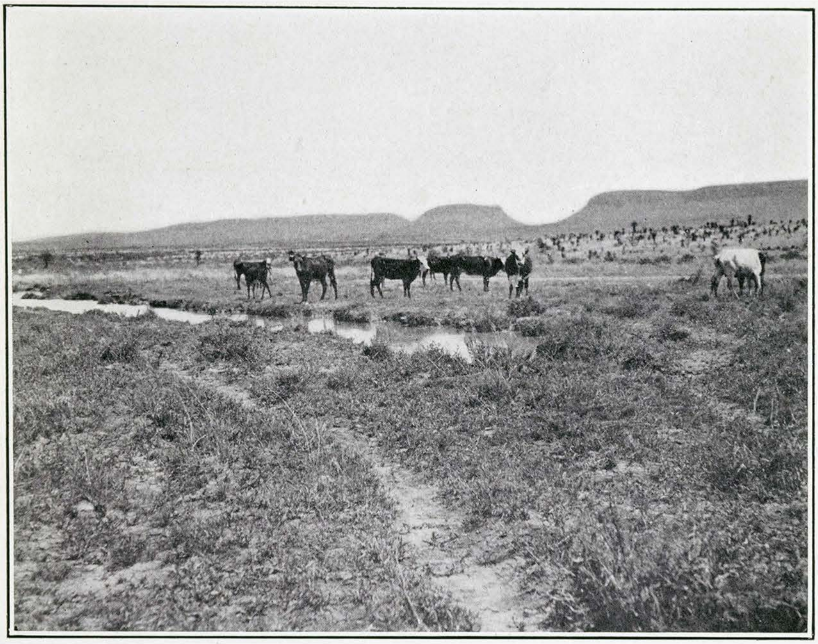
From these results the outlook is not bright, yet it is likely that other wells will find water in Eagle Flat, but the catchment area is small and a large amount should not be expected (Pl. VIII, *A*).

UNDERGROUND WATER IN THE DIABLO PLATEAU.

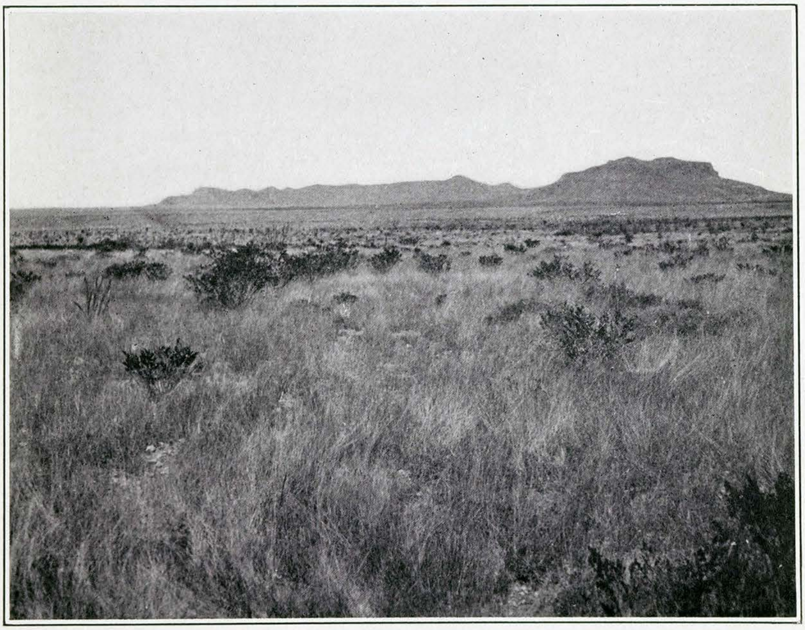
The Diablo Plateau is the driest part of the area under consideration, and this is largely due to its topography and geology. The plateau has been described as a flattish upland underlain by low-lying rocks, chiefly non-magnesian limestones. The margins of the plateau are considerably dissected and have local names.

The low-lying, non-magnesian limestones that occupy by far the greater part of the plateau are covered with only a thin coating of limestone débris; the conditions, therefore, are unfavorable for the accumulation of ground water. The presence of impervious rock so near the surface and the absence of considerable porous material in which storm waters can be stored cause a large part of the rainfall to escape by evaporation. A number of unsuccessful wells, some of which have been put down in favorable localities to find ground water if it were present, emphasize the dryness of this large tract.

West of the Cottonwood Tree ranch and north of Black Mountain, three wells, 110, 140 and 250 feet deep, have been drilled in valleys where ground water might be expected to occur, but, after passing through a thin coating of surface material, limestone was penetrated in all without finding any water, or at least not enough to pump. In a less favorable



A. WATER HOLE FIVE MILES NORTH OF EAGLE FLAT STATION.
Diablo Mountains in the background.



B. VIEW OF GRASS ON UNIVERSITY ALPHABET BLOCKS.
Black Mountain in the background.

locality, immediately south of Black Mountain, another well was sunk, in 1903, in limestone to a depth of 102 feet. Other shallow wells have been put down southeast of the Cornudas Mountains; these, too, went through a thin surface covering and into limestone without finding water.

The non-magnesian character of the underlying limestone, which is a dense, non-porous rock, offers little hope of finding much water in it. A well about 6 miles east of Cerro Alto Peak, near the New Mexico line, is further evidence. This well was sunk 850 feet in limestone of the Hueco formation and no water was found. It must be borne in mind, however, that limestone frequently is cavernous and often contains open underground channels. Though none of these have been found in the Diablo Plateau their presence is possible, and it may be that such local supplies may yet be found.

In this region on the eastern slope of the Hueco Mountains, extending to Black Mountain is located the great undivided tract of State University land (Pl. VIII, *B*), which comprises the so-called Alphabet Blocks that contain 680 square miles. The grass on this land is luxuriant,[46] but little or no underground water has been found. More prospecting should be done for ground water in the beds of the arroyos, that have a considerable drainage area and are fairly well covered with detritus. There is also a bare chance of obtaining water from the Cox formation, which outcrops at the base of the plateau north of Finlay Mountains and extends northward an unknown distance, but certainly not north of the northern limit of the Fredericksburg rocks. This is only a chance, however, for the catchment area of this sandy formation is small, and apparently the formation fades away to the north and it may not be found by a well on the University land.

The most favorable opportunity for developing these Alphabet Blocks appears to be by the construction of tanks to catch storm waters and by the extension of all possible supplies of water toward the University land. There are few especially favorable sites for tanks on this land, yet not far away are better opportunities in the Hueco, Cornudas, Sierra Tinaja Pinta, Black and Diablo mountains.

Water is obtained at several localities about the margins of the Diablo Plateau. The Hueco tanks at the northwestern end of the Hueco Mountains, about 30 miles from El Paso, are unique and furnish an abundant supply of fresh water (Pl. IX, *A*). These tanks are erosion hollows in a large, dike-like mass of igneous rock. Dams have been constructed across the hollows, and rain-water is thus impounded. There are a dozen of these tanks, large and small, in an area of about one square mile; four contain water all of the year, and two have elaborate cement dams. About 1000 cattle are watered here. In wet weather water collects in a

[46]The following is a partial list of grasses collected from the University land, identified by the Division of Agrostology, United States Department of Agriculture:

Aristida hookeri	Chaetochla composita
Aristida reverchoni	Muhlenbergia arenicola
Bouteloua curtipendula	Panicum obtusum
Bouteloua eriopoda	Scleropogon brevifolius
Bouteloua oligostachya	Sporobolus strictus

surface depression known as Cerro Alto Lake, which lies at the east base of Cerro Alto about 5 miles east of Hueco tanks, but this is only a temporary source of supply, and there are a few small water holes in the Southern Hueco Mountains, as mapped.

There are several springs in and about the Cornudas Mountains, only one, however, is known to occur within Texas. This is Washburn Spring, which is shown on the map. The spring occurs about 200 feet up the southeast side of the flat-topped Washburn Mountain. The water appears to issue at the contact of igneous rocks with flat-lying Washita sediments. This water is of excellent quality, but the spring is feeble. It is estimated that only about 20 head of cattle can be supplied here.

Several tanks collect storm water between the Cornudas and the Diablo Mountains, and the largest ranch tank in the area under consideration is situated on the northwestern slope of the Diablo Mountains, about 7 miles southeast of Black Mountain. This tank is reported to supply about 2000 head of cattle (Pl. IX, *B*). Other successful tanks are situated farther south on the western slope of the Diablo Mountains, as mapped.

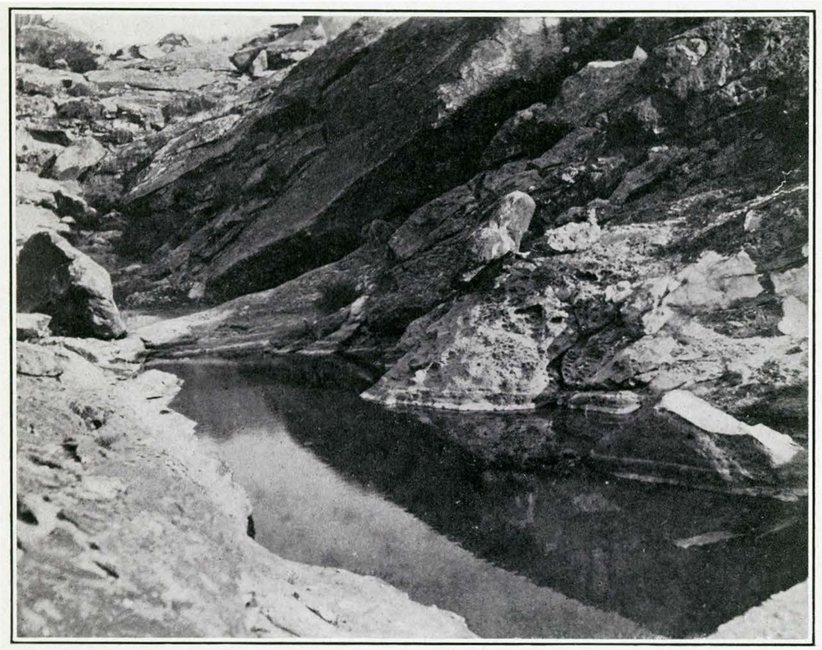
A few successful wells have been sunk in and adjacent to the southern Diablo Mountains; these tap water that is stored in the relatively thick débris of Deer Creek Valley. At Bounds' ranch (Pl. X, *A*), about 10 miles north of Allamoore, there are three wells that supply good, fresh water. The wells range from 23 to 86 feet in depth. At Millican's ranch, about 4 miles north of Allamoore, there are two shallow wells about 22 feet deep. In the same valley, 3 miles north of Allamoore, the Texas and Pacific Railroad Company has six wells that are reported to supply about 50,000 gallons a day of good water. These wells are connected by tunnels. The deepest, in which a steam pump is situated, is 70 feet deep and, below 8 feet of surface material, is in gravel all the way. Water was struck at 50 feet and rises from 5 to 12 feet above this level.

There is more or less water in the valley of Sulphur Draw in which Cannon's ranch is located, about 10 miles north of Van Horn. The bed rock is the pre-Cambrian, fine-textured red sandstone.

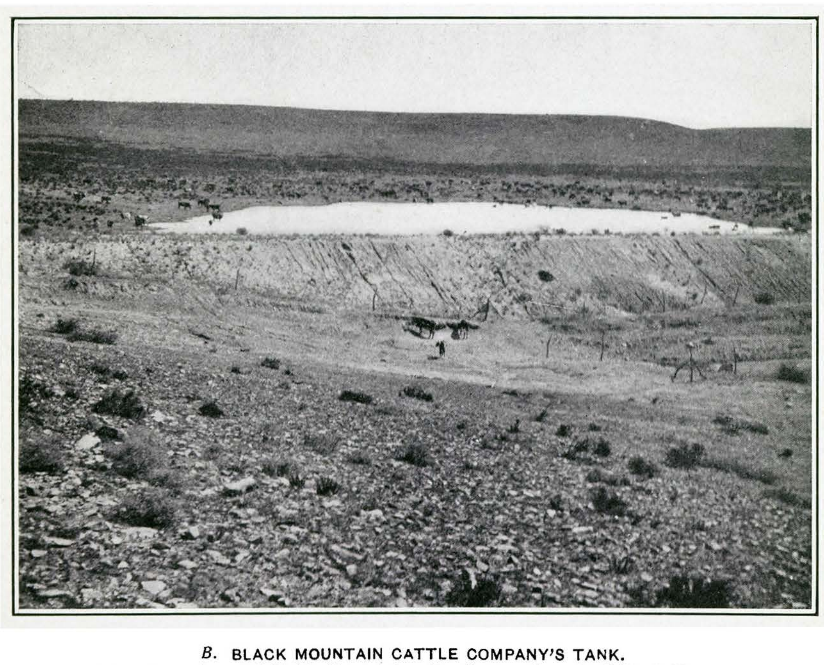
This rock is considerably cracked by joints and readily absorbs water. Several seep springs occur along the draw, and at Cannon's ranch is a successful well 30 feet deep in which the surface of the water stands at a depth of 6 feet. The location of successful wells in this valley is somewhat uncertain because of the broken nature of the rocks. Below Cannon's ranch a small dike cuts across the valley and seems to be effective in impounding underground water, so that a good supply is here available.

On the most northerly of the Sierra Blanca peaks a small spring was discovered in the summer of 1903. This spring is situated on the north side of the peak, about 400 feet above the road. The water, which is of excellent quality, occurs in débris on the mountain side, and appears to issue at the contact of Washita sediments with the igneous rock of the peak. There is little reason to expect that the supply of water is large, for the collecting area is very limited. When visited, the water stood 5 feet deep in a shallow hole.

Southwest of the Sierra Blanca, on the south side of the railroad at



A. HUECO TANKS 25 MILES NORTHEAST OF EL PASO.



B. BLACK MOUNTAIN CATTLE COMPANY'S TANK.
Northeastern slope of Diablo Mountains, 7 miles southeast of Black Mountain.

Lasca and considerably outside of the Diablo Plateau, there is an unusual occurrence of underground water. The Southern Pacific Company has dug a well 12 by 12 feet at the surface and 150 feet deep. This well is excavated in granite rock, at the north end of the Quitman Mountains. At the botton of the well there are about 90 feet of tunneling. The rock is much jointed in different directions and it is in these joint cracks that the water occurs. It said that if the water be allowed to collect it will rise to within 35 feet of the surface. This is the most conspicuous occurrence in this region of underground water occurring in cracks and crevices in massive rock instead of in the interstices of porous rock.

The Southern Pacific Company sank a well 1140 feet deep close to the railroad at Lasca in 1900. The log of this well is not reported, but it is said that limestone was struck below 100 feet of unconsolidated surface material. A little water was found at 600 feet, but the well was abandoned.

In the Finlay Mountains there are two successful wells at Finlay's ranch. These wells are about 115 feet deep, and water is found at a depth of 96 feet in sandstone of the Cox formation. Records of the wells were not obtained. The water is of good quality, but no analysis of it has been made. Both a windmill and a pump, worked by a gasoline engine, are used, and it is said that 2500 cattle are watered here.

There is a fair chance that a limited quantity of water under some pressure can be found by drilling into the Cox formation elsewhere along the flanks of the Finlay Mountain Dome. In prospecting, care should be taken to choose a location above which a considerable area of sandstone outcrops. A locality north of Malone Station adjacent to the mountains might prove favorable, but in that vicinity it must be considered that there are a number of dikes that tend to cut off the water supply below them; then, too, this region has been so disturbed that it can not be predicted what rocks are beneath the cover of unconsolidated materials.

UNDERGROUND WATER IN THE HUECO BASIN AND THE RIO GRANDE VALLEY.

The Hueco Basin, it will be recalled, is occupied by over 2000 feet of unconsolidated materials into which the Rio Grande has cut its valley some 250 feet. The occurrences of water in this area will be described under two heads, Mesa water and Valley water.

Mesa Water.—The mesa northeast of El Paso is practically flat. No pronounced drainage ways indent it and extensive deposits of caliche lie at or near the surface. Very little shallow ground water has been found over a large part of the Hueco Basin in Texas, nevertheless there is a good supply of an excellent quality of deep-seated underground water on the mesa.

This mesa water has been exploited in the vicinity of Fort Bliss, where there are a number of successful wells. The following log,* reproduced as received from the driller, shows the sequence of the deposits in a well immediately north of the reservation:

*Furnished by the International Water Company.

Log of well in Section 17, Block 81, Township 2, El Paso county.

	Thickness, feet.	Depth, feet.
Soil	2	2
Hard "Caliche" clay and rock	8	10
Dry fine sand and gravel	28	38
Soft "Caliche" clay	4	42
Fine dry sand	8	50
Soft "Caliche" clay	2	52
Fine dry sand	12	64
Red clay	42	106
Dry sandy clay with small "rock kidneys"	44	150
Red clay	30	180
Tough red clay	50	230
Fine sand with water	6	236
Fine sand and clay, supposed to contain water	10	246
Tough yellow clay	8	254
Dry fine sand, no water	8	262
Yellow clay	56	318
Fine sand, supposed to contain water	14	332
Hard yellow clay	44	376
Sandy clay with hard red "clay kidneys"	14	390
Dry sandy clay	18	408
"Sediment clay"	39	447
Fine sand, supposed to contain water	3	450
Red clay	140	590
Hard clay with small "rock kidneys"	18	608
"Joint" brown clay	22	630
Hard sandy clay	46	676
"Sediment" clay	44	720
"Stratified" clay	148	868
"Joint" clay	2	870
Brown and red clay	42	912
"Stratified" clay	41	953
Hard "stratified" clay	37	990
Brown clay	10	1000
Hard "stratified" clay	30	1030
Brown "sediment" clay, hard	42	1072
Soft sand rock	4	1076
Very hard brown clay	83	1159
Very hard brown sandy clay	30	1189
Hard sandy clay	109	1298
Dry gravel	12	1310
Brown clay	251	1561
"Rock"	57	1618
Soft "rock"	54	1672
"Rock"	86	1758
Hard and soft strata of soft "rock"	33	1791
Very soft "rock"	49	1840
Very hard clay	13	1853
Supposed sandstone	30	1883

Hard conglomerate	23	1906
Soft "rock"	39	1945
Hard conglomerate	35	1980
Hard sandy clay	28	2008
Red clay	120	2128
Soft "rock"	27	2155
Hard brown clay	130	2285

This is the deepest of seven wells recently put down by the International Water Company with the intention of supplying El Paso with mesa water. "Bed rock" was not reached, and no water was found below 450 feet from the surface. The other wells range in depth from 300 to 700 feet and show little variation. The principal water horizon is a bed of fine sand averaging 20 feet thick and occurring at a depth of 230 feet from the surface. Tests have not yet been made of the capacity of these wells.

Other near-by wells are: Major Logan's well, 1 mile northwest of Fort Bliss, 300 feet deep; two wells at the Fort Bliss station of the Chicago, Rock Island and El Paso Railroad, 260 and 420 feet deep, respectively; two wells of the Federal Copper Company, 1 mile south of Fort Bliss, 289 feet deep; the army post well, 312 feet deep; and four wells immediately south of Fort Bliss owned by the Southern Pacific Company. The latter wells supply the entire needs of the railroad at El Paso, and Superintendent G. W. Hawkes makes the following statement concerning them:

The depths of the wells are respectively 299, 300, 301 and 303 feet. They are ten inches in diameter, and water stands in them 50 feet deep. In a test made in August, 1903, four 15-horsepower gasoline engines pumping continuously delivered 256,996 gallons in 24 hours. The average daily capacity of the wells in January, 1904, was 223,208 gallons. These wells have been in operation four years with no diminution in the supply.

The above tests demonstrate an abundance of water on the mesa, but the maximum available amount is not known.

The quality of the mesa water in the vicinity of Fort Bliss is excellent, as shown by the following analysis:

Analysis of water near Fort Bliss. Army post well.[47]

	Parts per 100,000.
Silica, iron and alumina	2.34
Lime	4.62
Magnesia	2.36
Soda	6.86
Potash	0.77
Sulphur trioxide	4.40
Carbon dioxide	8.80
Chlorine	1.31
Crystal water and organic matter	.24
Total solids	31.40

[47]Furnished by the El Paso Chamber of Commerce.

El Paso Rock Island Route wells.[48]

	No. 1.	No. 2.
	Parts per 100,000.	
Silica	2.50	2.50
Alumina	0.20	0.50
Calcium carbonate	9.50	11.00
Magnesian carbonate	6.43	9.07
Sodium sulphate	7.74	9.27
Sodium carbonate	3.01	2.31
Sodium chloride	3.62	5.85
Total	33.00	40.50

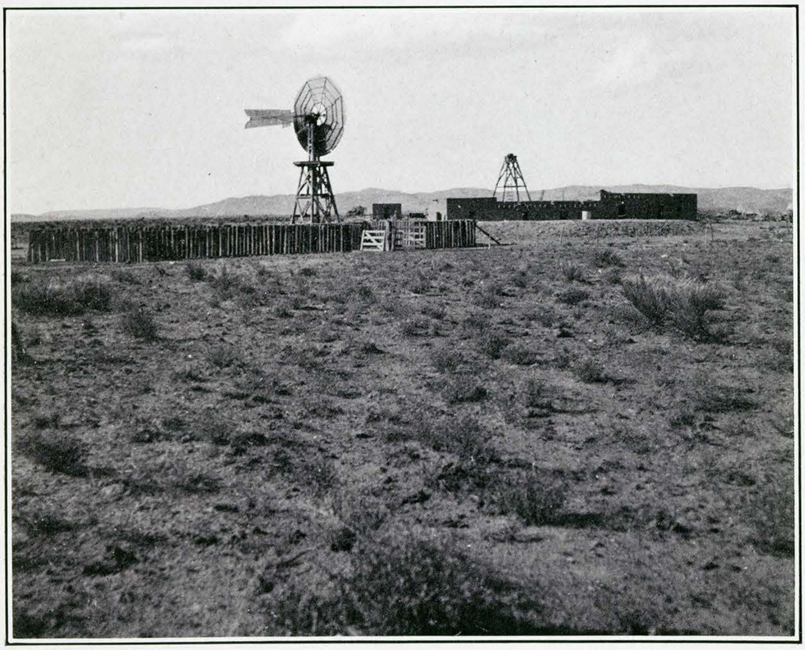
Besides these wells on the mesa near Fort Bliss, a number of other wells have been sunk for ranch purposes, as shown on the map, between the Franklin and Hueco mountains. These range in depth from 300 to 450 feet and apparently tap the Fort Bliss water horizon. Both windmills and gasoline engines are used to bring the water to the surface. A few unsuccessful wells have been sunk to 600 feet. In these water was found, but in quicksand, that caused so much trouble that the wells had to be abandoned. The wells about 10 miles northeast of Clint belonging to Carpenter Brothers and Sharpe are examples of the successful recovery of water from quicksand that gave much trouble (Pl. X, *B*). Water which rises 65 feet was struck at a depth of 410 feet. The log of one of these wells follows:

Log of Carpenter Bros. & Sharpe's well, 10 miles northeast of Clint.

	Thickness, feet.	Depth, feet.
Sand	2	2
"Caliche"	15	17
Coarse sand	15	32
Hard reddish clay	26	58
Coarse gray sand	97	155
Fine hard sand	20	175
Sand	30	205
Clay	7	212
Hard sand	10	222
Brittle clay	20	242
Quicksand	20	262
Loose sand	10	272
Pack sand	20	292
Loose sand	16	308
Clay	14	322
Sand	8	330
Clay	16	346
Sand	10	356

[48] Furnished by Mr. Chas. B. Eddy.

A. BOUND'S RANCH, DIABLO MOUNTAINS, 10 MILES NORTH OF ALLAMOORE.



B. CARPENTER BROS.' AND SHARPE'S WELLS IN THE HUECO BASIN, ten miles northeast of San Elizario.

Clay	24	380
Fine sand (water horizon)	30	410
Clay	54	464
Coarse sand	2	466
Fine sand and clay	27	493

The quantity of the water in these wells outside of the Fort Bliss area has never been measured, but it is reported sufficient for ranch needs. The quality is excellent, but not far north of the New Mexico line in the northward continuation of the Hueco Basin wells strike strongly saline water. At Hereford, New Mexico, 14 miles north of Fort Bliss, the railroad has two wells 360 feet deep, in which the water contains a considerable amount of salt, but very little other soluble matter, as shown by the following analysis. But at Hueco, 6 miles farther northeast, the water in a well 431 feet deep contains abundant dissolved salts. Similar strongly saline waters are found thereabouts:

Analyses of water at Hueco and Hereford, New Mexico.[49]

Hereford well.	Parts per 100,000.
Silica	3.00
Alumina	2.00
Calcium carbonate	9.00
Calcium sulphate	5.45
Magnesium sulphate	1.36
Magnesium chloride	4.04
Sodium chloride	26.90
Water of crystallization	1.25
Total solids	53.00

Hueco well.	Parts per 100,000.
Silica	1.80
Lime	32.45
Magnesia	7.24
Soda	89.53
Sulphuric acid	78.19
Carbonic acid	2.75
Chlorine	71.94
Potash	1.47
Water of crystallization	32.63
Total solids	318.00

The depth at which water was first found in most of the wells outside of the Fort Bliss area has not been recorded and there is little evidence on which to base the position of the water-bearing horizon throughout the extent of the Hueco Basin. The depths of the different wells, however, allowing for their varying surface elevations and assuming that the water comes from one horizon, suggest that the water-bearing horizon is not much inclined. Yet the fact that the water rises a number of feet in many of the wells indicates that it is under some pressure and implies at least a local dip. Not knowing surely the position of the unconsolidated beds of the Hueco Basin, it is impossible to predict with certainty; but from the apparent slight inclination of the beds, and especially considering the results of the wells already sunk, there is not a bright outlook for securing artesian water on the mesa. It should be noted, however, that a deep well has not been sunk in a critical part of the valley towards the center of the basin.

[49] Furnished by Mr. Chas. B. Eddy.

The source of the mesa water is not readily apparent. Presumably little rainwater percolates directly downward to the water horizon over much of the surface of the mesa. The common presence of caliche and other relatively impervious materials at or near the surface and the occurrence of several beds of clay above the water horizon, shown by well records, do not favor such an origin. The great extent of the Hueco Basin northward suggests that much of the mesa supply comes thence. But the distinct difference in composition of the waters northward and southward of an indefinite line not far north of the State boundary implies that, for a considerable extent, at least, the underground water of the northern part of the basin does not drain into Texas. The distribution of these different waters, however, has not been defined. Possibly the occurrence of the saline waters is local and underground communication toward the western margin of the basin may be maintained, so that part of the mesa water may come from New Mexico. However this may be, an important source of the water seems to be due to absorption by porous deposits along the periphery of the basin. On the eastern flank of the Franklin and Organ mountains a relatively large amount of storm water courses down the slope and along the base of the mountains. This water is imbibed at the margin of the basin by sand and gravel, in which it slowly percolates to the porous deposits in which it is found.

Along the margins of the Hueco Basin a few wells have been sunk into bed rock without success, and there is little evidence for expecting better results in the future. In 1886 a dry well is reported to have been sunk 800 feet in the igneous rock about 2 miles northwest of El Paso, and in 1900 a 500-foot well was drilled in limestone (?) about 17 miles northeast of San Elizario without success.

Valley Water.—In the valley of the Rio Grande there is a comparative abundance of water. Measurements of the river at El Paso have been made for a long time. The following tables of results, in 1900, will indicate general conditions. The measurements were made at Courchesne's lime kiln, about 4 miles above El Paso:

Rio Grande Measurements.[50]

Discharge measurements of Rio Grande near El Paso, Texas.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1900.	*Feet.*	*Sec.-ft.*	1900.	*Feet.*	*Sec.-ft.*
January 3	5.40	90	February 27	5.40	89
January 6	5.40	93	March 3	4.50	13
January 9	5.40	89	May 17	6.50	518
January 11	5.80	151	May 18	7.50	908
January 13	6.50	341	May 22	7.50	769
January 16	6.20	246	May 26	9.30	2,120
January 18	5.90	143	May 28	9 20	2,146
January 22	5.50	102	June 1	9.60	2,369
January 24	5.60	111	June 6	10.40	3,500
January 27	5.60	113	June 9	10 40	3,319
January 30	5.50	94	June 10	10 30	2,686
February 1	5.50	100	June 13	9.50	1,680
February 3	5.40	90	June 18	8.30	957
February 6	5.40	88	June 22	7.10	358
February 8	5.50	105	June 25	6.20	131
February 10	5.60	108	June 27	5.90	95
February 13	5.60	117	June 30	5.40	17
February 15	5.50	101	September 9	8.40	1,164
February 19	5.80	134	September 13	9.40	2,005
February 22	5.40	94	September 17	8 70	1,278
February 24	5.30	77	September 22	6.20	126

Daily gage height, in feet, of Rio Grande near El Paso, Texas, for 1900.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Sept.	Dec.
1	5.40	5.50	5.15	4.30	4.30	9 65	5.10	(*a*)	(*b*)
2	5.40	5.40	4.90	4.30	4.30	9.65	5.00	....	....
3	5.40	5.40	4.65	4.30	4.30	10.05	5.00	....	....
4	5.40	5.40	4.35	4.30	4.30	10.30	5.00	....	....
5	5.45	5.40	(*c*)	4.30	4.30	10.40	5.00	....	....
6	5.45	5 40	(*c*)	4.30	(*c*)	10.45	5.00	....	....
7	5.40	5.50	(*c*)	4.30	(*c*)	10.45	5.00	....	....
8	5.40	5.50	(*c*)	4.30	(*c*)	10.40	(*a*)	....	....
9	5.45	5 50	(*c*)	4.30	(*c*)	10.40	....	8.00	....
10	5.65	5.55	(*c*)	4.30	(*c*)	10.35	....	5.90	....
11	5.80	5.60	(*c*)	4.30	(*c*)	10.10	....	5 10	....
12	5.75	5.60	(*c*)	4.30	(*c*)	9.75	....	6.15	....
13	6.45	5.60	(*c*)	4.30	(*c*)	9.40	....	9.10	....
14	6.35	5 60	(*c*)	4.30	(*c*)	9.30	....	8.35	....
15	6.30	5.50	(*c*)	4.30	(*c*)	9.25	....	7.85	....
16	6 15	5.50	(*c*)	4.30	(*c*)	9.15	....	7.75	....
17	5.95	5.50	(*c*)	4.30	6.80	8.45	....	8.50	....
18	5.85	5.90	(*c*)	4.30	7.55	8.30	....	7.75	....
19	5.70	5 80	(*c*)	4.30	7 65	7.90	....	7.05	....
20	5.60	5.70	(*c*)	4.30	7.65	7.60	....	6.35	....
21	5.60	5.55	(*c*)	4.30	7.65	7.35	....	6.30	....
22	5.50	5.40	(*c*)	4.30	7.55	7.00	....	6.15	5.05
23	5.50	5.40	(*c*)	4.30	7.40	6.75	....	6.20	5.40
24	5.60	5.35	4.65	4.30	8.25	6.45	....	5.60	5.40
25	5.60	5.30	4.55	4.30	9 80	6.25	....	5.50	5.40
26	5.60	5.40	4.40	4.30	9.30	6.05	....	5.40	5.40
27	5.60	5.40	4.30	4.30	9.25	5.90	....	5.40	5.40
28	5.60	5.40	4.30	4.30	9.20	5.75	....	5.25	5.35
29	5.55	....	4.30	4.30	9.10	5.55	....	5.10	5.15
30	5.50	....	4.30	4.30	9.30	5.30	....	5.00	5.10
31	5.50	....	4.30	....	9.40	....	....	....	5.10

a River dry from July 8 to September 9.
b River dry from October 1 to December 23.
c River dry.

[50] United States Geological Survey, Water-Supply Paper No. 50, p. 353. For other tables and references, see Water-Supply Paper No. 37.

During part of the year, river water is available for irrigation in the valley and ditches extend from El Paso to Fabens, as described in the report on "Irrigation Systems of Texas."[51] Increasing use of the water up stream, in recent years, has seriously interfered with the flow and it has become necessary to seek a new supply to supplement river irrigation during the driest months. Relief has been found in the "underflow."

The underflow of the Rio Grande is a great body of slowly moving water contained in sand and gravel beneath the surface following the course of the river. This water reaches its underground position by percolation from the river throughout its course, but especially in those parts where the stream runs over porous sands and gravel; in clay-covered stretches comparatively little water percolates downward. Also the underflow is contributed to by underground drainage tributary to the valley. Many facts remain to be learned concerning the underflow, especially its amount and rate of movement are unknown. It is known, however, that there is a great quantity of water here available.

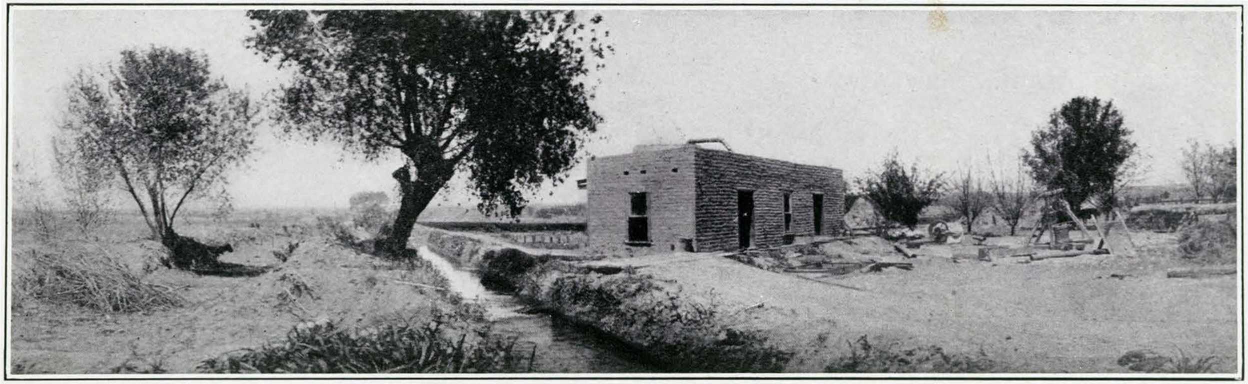
The valley is many miles wide, the depth to bed rock is considerable, and the varying character of the underlying porous materials is generally unknown. In the restricted part of the river's course, in the pass about 4 miles above El Paso, however, conditions are different. The river is confined by rock walls to narrow limits, and the depth to bed rock, as well as the nature of the unconsolidated materials, has been ascertained by drills put down by the International Dam Commission. Conditions here are favorable, therefore, for making measurements that will at least give approximate figures for the quantity of the underflow, and it is proposed to begin such measurements at an early date, though it remains to be proved that the entire underflow goes through the pass.

Sections in the pass at El Paso show that the depth to bed rock there averages about 55 feet beneath the river bed. The different sections show that conditions are not uniform across the narrow valley, but that there is a dove-tailing of the deposits. Much sand and gravel are present, but apparently there is very little clay. The following section is typical:

Section in bed of Rio Grande, about 4 miles above El Paso.

	Feet.
6. Sand	27
5. Gravel	12
4. 5 layers of alternating sand and gravel	2
3. Gravel	8
2. 10 layers of alternating sand and gravel	5
1. Sand	1
Bed rock.	
Total	55

[51] T. U. Taylor, Water-Supply and Irrigation Paper No. 71, United States Geological Survey, 1902.



PUMPING PLANT OF J. A. SMITH, 8 MILES EAST OF EL PASO.
Photograph by J. H Campbell.

This shallow depth prevails only at the pass, below and above which the depth is considerable, but unknown. In 1896, a well was put down in the valley about a mile and a half below El Paso to a reported depth of 1693 feet. This work was done by the city in the hopes of finding artesian water. Bed rock was not reached, and, although plenty of water was encountered, no artesian flow was found.

Down the river from El Paso, within the area covered by the alluvium, extending to below Fort Hancock, many shallow wells have been sunk. These supply the towns of Ysleta, San Elizario, Clint, Fabens and Fort Hancock and the scattered ranches in the valley. The railroads also supply their engines with water from shallow wells at Fabens and at Fort Hancock.

At Fabens, the railroad well is 20 feet in diameter and 35 feet deep, and supplies about 50,000 gallons a day. At Fort Hancock, the well is close to the river, about a mile southwest of the station. This well is 41 feet deep and one 9-inch and four 6-inch casings extend 20 feet farther down. About 80,000 gallons a day are pumped from this well.

An important use of the valley wells is for irrigation. A few irrigation pumping plants have been in successful operation for three or four years and within the past year many new ones have been started. In May, 1904, it was estimated that 25 pumping plants were in use below El Paso.

The underflow is utilized for irrigation, chiefly to supplement the river water after the latter has been exhausted. Pumping has to be resorted to only for a fraction of the year, from four to six months being about the average. Garden vegetables, fruit and alfalfa are the principal products.

These valley wells average 60 feet in depth. The water stands about 15 feet from the surface and is commonly found to occur from this horizon down to the bottom of the wells, which is usually in coarse gravel. Gasoline is mostly used as a fuel, but it may soon be replaced by crude oil.

J. A. Smith's pumping plant, about 8 miles below El Paso, is typical (Pl. XI). Mr. Smith has three wells, ranging from 60 to 72 feet in depth, in which water stands at about 15 feet from the surface. One 8-inch and two 6-inch pipes, with attached strainers, extend to the bottom of the well. A centrifugal pump is situated in one of the wells, near water level, and is connected with the other two. A 28-horsepower Fairbanks and Morse engine, originally intended for gasoline, is attached to the pump. The engine is now adapted to the use of crude oil and is reported to work successfully, at a considerable saving, compared with the use of gasoline. Mr. Smith estimates that he pumps between 1100 and 1200 gallons a minute. He raises alfalfa exclusively, and has about 100 acres under cultivation.

The quality of the underflow water is indicated by the following analysis:

Analyses of the Rio Grande "underflow" below El Paso, by E. M. Skeats.[52]

	Parts per 100,000. Hadlock Well, 2 m. east of El Paso.	Courchesne Well, Ysleta.
Silica	2.50	3.00
Alumina and iron	1.00	10.00
Calcium carbonate	11.50	15.00
Magnesium carbonate	4.53	3.01
Potassium sulphate	5.80	......
Sodium sulphate	16.14	37.80
Sodium carbonate	2.80	12.13
Sodium chloride	30.15	23.30
Water of crystallization and organic matter	0.25	1.76
Total solids	74.62	106.00

Analyses of water from J. S. Porcher's well, 8 miles below El Paso, by Arthus Goss.[53]

	Parts per 100,000. No. 1.	No. 2.
Silica, alumina and iron	3.12	1.68
Lime	28.92	19.32
Magnesia	7.29	5.89
Soda	33.87	28.62
Potash	2.61	2.26
Sulphur trioxide	30.34	31.34
Chlorine	43.86	20.75
Carbon dioxide	12.07	11.52
Water of crystallization and organic matter	17.83	7.31
	179.91	128.69
Oxygen equivalent of chlorine	9.91	4.69
Total solids	170.00	124.00

Those who have pumping plants are enthusiastic over the results. It has been demonstrated that the underflow is abundant, but a definite statement of the available amount can not now be made.

El Paso Water Supply.—The following list gives statistics concerning a number of wells in El Paso:

[52]The writer is indebted to Mr. Skeats for many courtesies and for considerable information concerning the region covered by this report.

[53]Bulletin No. 34, New Mexico College of Agriculture, 1900.

Partial list of wells in El Paso.

Name.	Depth of well, feet.	Depth to water in well, feet.	Diameter of well.	Pump.	Quantity pumped.	Quality of water.
El Paso Water Co.	65	20 to 60	18 ft. top 14 ft. bot	Steam	1,500,000 gallons per day	Fair
El Paso & Northeastern Railway Co.	269	8?	?	Steam	80,000 gallons per day	Good
El Paso Ice and Refrigerator Co.	403	100	8 in	Steam	250,000 gallons per day	Good
Texas and Pacific Railway Co.	109	17	10 in	Steam	2,500 gallons per hour	Good
Texas and Pacific Railway Co.	65	45	8 in	Steam	10,000 gallons per hour	Fair
A. T. & S. F. Ry. Co.	100	26	10 in	Steam	New well not yet tested	Fair
A. T. & S. F. Ry. Co.	360	?	10 in	Steam	Insufficient	Poor
Consumers Ice Co.	45	25	6 in	Steam	Not measured	Fair
Gas Plant	60	36	6 ft	Steam	10,000 gallons per day	Fair
Light and Power Co.	70	60	8 ft	Steam	18,000 gallons per day	Fair
El Paso Laundry Co.	50	25	6 in	Steam	15,000 gallons per day	Fair
El Paso Dairy Co.	65	45	3 in	Gasoline	20,000 gallons per day	Fair
Franklin Dairy Co.	48	20	2½ in	Windmill	1,000 gallons per day	Good
El Paso Brewery	54	?	10 in	Steam	New well not yet tested	Good
E. Moye	350	125	6 in		Abandoned	Poor
Newman & Austin	700	300?	8½ in		New well not yet tested	Good
C. C. Black	52	22	1½ in	Windmill	Domestic use	Fair
H. F. Stacy	27	20	1½ in	Windmill	Domestic use	Fair
G. W. Parker	62	10	4 in	Windmill	Domestic use	Fair
Mrs. Ball	65	20	1½ in	Windmill	Domestic use	Fair
M. F. Riley	154	20	6 in	Gasoline	Domestic use	Good
J. H. Logan	40	14	2 in	Gasoline	2,000 gallons per hour	Poor
Mrs. Kendall	44	20	5 in	Gasoline	Domestic use	Good
W. Allen	70	20	2½ in	H'nd p'mp	Domestic use	Fair
Mr. Heid	59	20	2 in	Windmill		Good
J. Drume	54	20	6 in	Gasoline	Domestic use	Good

Considering its arid surroundings, El Paso is exceptionally well provided with water. There are three distinct sources: shallow ground water, mesa water, and the Rio Grande underflow. The latter furnishes the main city supply, but the quality is not very good; mesa water is largely utilized for drinking, and there is a likelihood of its use becoming more general; the shallow ground water generally is of poor quality, and comparatively is unimportant.

The wells of the El Paso Water Company, the Gas Plant, the Light and Power Company, the El Paso Laundry Company, the Consumers Ice Company, and the El Paso Dairy Company supply large quantities of water and are typical of the many wells, only partly listed, that tap the underflow of the Rio Grande. In these wells the water occurs in gravel at depths varying from 15 to 60 feet. The surface is commonly underlain by clay to depths of from 15 to 60 feet from the surface. The water level varies with the stage of the river and is distinctly lowered in wells by powerful pumps. At the city waterworks, for instance, in the dry season the water level is said to be lowered by pumping to within five feet of the bottom of the well, and it is reported to take four or five hours after the cessation of pumping for the water to rise to the normal level in the well.

The abundance of water obtained from the underflow in El Paso would leave little to be desired if the quality were good, but unfortunately this is not the case. The following analysis of hydrant water made for the Chamber of Commerce is said to be typical of the El Paso supply:

Analysis of El Paso hydrant water.

	Parts per 100,000.
Silica, alumina and iron	2.45
Lime	22.55
Magnesia	6.14
Soda	33.76
Potash	2.20
Sulphur trioxide	28.21
Chlorine	40.56
Carbon dioxide	8.90
Water of crystallization and organic matter	10.00
	154.77
Oxygen equivalent of chlorine	9.17
Total solids	145.60

Analyses of Rio Grande water from Mesilla Park, New Mexico, 20 miles north of the Texas boundary, were systematically made at the Agricultural College there in 1893-94, samples being collected daily for a year. The results show an average of 44.11 parts of total solids per 100,000, the amounts ranging from 19.64 to 79.25.[54] But analyses made at different times show considerable differences: thus, in July, 1899, the water contained 161.50 parts of total solids per 100,000; in August, 191.10, and in December, 53.60. It should be noted, however, that the higher amounts were obtained from small flows that came down the river after periods of complete dryness.

The underflow in general contains more dissolved salts than the river water. This is shown in the valley proper between Mesilla Park and Las Cruces by the results of 29 analyses, the average of total solids per 100,000 being 81.73, while analyses of water away from the immediate vicinity of the river adjacent to the foothills contiguous to the valley between Mesilla Park and Las Cruces average 123.65 parts of total solids per 100,000.[54] These figures are lower than the results at El Paso, but the higher amounts of total solids there obtained appear to be due to local conditions.

A number of shallow wells in and about El Paso show the presence of considerable amounts of sodium chloride. The Foundry well, the Moye well, the Santa Fe well, and several others, are reported to contain water with abundant salt, and an analysis from a well belonging to Mr. Z. White, in the valley about 10 miles above El Paso, shows a large amount, as follows:

[54]Bulletin No. 34, New Mexico College of Agriculture, 1900.

Analysis of water from White's well, in the Rio Grande Valley, about 10 miles above El Paso, by E. M. Skeats.

	Parts per 100,000.
Silica, alumina and iron	10.66
Calcium carbonate	32.50
Calcium sulphate	309.80
Magnesium sulphate	4.02
Sodium sulphate	210.32
Sodium chloride	1052.00
Water of crystallization and organic matter	100.70
Total solids	1720.00

Though the city water supply from the underflow is poor its quality can be improved by chemical treatment. The calcium and magnesium salts, which render the water hard and ill-suited for domestic and boiler uses, can be removed by precipitation as carbonates, by the addition of lime or caustic soda and sodium carbonate in amounts proportionate to the analyses. These methods are used in many households, by the laundries, and the Southern Pacific Company thus treats its water for locomotive use at Fabens and Fort Hancock.

Besides the Rio Grande underflow, El Paso is fortunate in having a considerable supply of comparatively soft water available on the near-by mesa, as already referred to. Efforts are being made to supply the city with this water, but it remains to be proved that the amount is sufficient.

Recently, good water of a quality similar to that found on the mesa, and possibly at least partly derived from it, has been obtained in wells in the eastern part of the city, conspicuous among which are the wells of the El Paso and Northeastern Railway Company and the El Paso Ice and Refrigerator Company. In these an inferior quality of water was encountered at shallow depths, below which good water occurs under some pressure. At the ice plant the inferior shallow water occurs down to about 100 feet from the surface, where it is separated from the good, deeper-seated water by a bed of clay about 9 feet thick. The following analysis is said to be typical:

Analysis of water from the El Paso Ice and Refrigerator Company's well, by E. M. Skeats.

	Parts per 100,000.
Silica	0.50
Alumina	trace.
Lime	2.23
Magnesia	3.00
Soda	8.98
Chlorine	5.31
Carbonic acid	5.72

Sulphuric acid	4.45
	30.19
Oxygen equivalent to chlorine	1.19
Total solids	29.00

Water of good quality is reported from several new wells in East El Paso, among which may be mentioned the Rhoden, Kendall, Allen, Wright, Drumé and the El Paso Brewery wells.

An analysis of the water from the Rhoden well is as follows:

Analysis of water from the Rhoden well, East El Paso, by E. M. Skeats.

	Parts per 100,000.
Silica	1.96
Alumina and iron	1.50
Calcium carbonate	2.00
Calcium sulphate	0.68
Magnesium sulphate	3.24
Sodium sulphate	6.73
Sodium carbonate	18.08
Sodium chloride	10.77
Water of crystallization and organic matter	0.50
Total solids	45.46

The quality of the hydrant water now supplied to El Paso can be improved upon by taking advantage of the mesa flow. Even if an insufficient amount for the city be found on the mesa, a supply of fairly good quality and probably adequate quantity can be obtained in the eastern part of the town from a combination of the mesa and the Rio Grande underflows.

The comparatively soft quality of the underflow obtained in the Hadlock well, about two miles below El Paso, appears to be due to seepage from the mesa. But in developing water east of El Paso care must be taken to avoid sewage contamination.

PARTIAL LIST OF WELLS.

(Numbers refer to location on map in pocket.)

No.	Name.	Depth feet.	Depth to water (feet).	Remarks.
1	El Paso	....	....	A number of wells. See text.
1a	City Artesian Prospect	1693	15 ?	Bed rock not reached. No artesian water.
1b	Hadlock	60	11	Valley wells east of El Paso supplied by underflow and used for irrigation. Types of valley pumping plant wells.
1c	Smith, J. A.	72	15	
1d	Porcher, J. S.	62	12	
1e	Cadwallader, J. F.	60	11	
1f	Smith, J. J.	60	14	
1g	Tibbetts, J.	60	15	
1h	Green, W. B.	65	12	
2	?	800	....	Dry.
3	Foundry Well	?	?	Abandoned.
4	Southern Pacific Co.	300-|-	250	Four wells. Capacity 223,208 gallons a day.
5	Fort Bliss	312	222	
6	Rock Island Railroad	260 420	....	
7	Major Logan	300	190	
8	International Water Co.	2,285	172 ?	Deepest of several wells. Artesian water not found.
9	Nations	200	180 ?	
10	Helm	219	198	
11	Lanoria	210-261	210-|-	Seven wells.
12	Morse	330	....	
13	Newman	375	....	
14	Newman	450	....	
15	Ysleta	60-|-	20-|-	A number of shallow wells.
16	San Elizario	60-|-	20-|-	A number of shallow wells.
17	Clint	60-|-	20-|-	A number of shallow wells.
18	Carpenter Bros. & Sharpe	30-|-	....	
19	Coles, O. C.	388	....	
20	Coles, O. C.	605	....	Abandoned.
21	Coles, O. C.	604	....	Abandoned.
22	Newman, H. L.	350	....	
23	Newman	450	....	
24	Newman	400	....	
25	Newman	375	....	
26	Newman	425	....	
27	Newman	450	....	
28	Carpenter Bros. & Sharpe	500-|-	410	Water in fine sand, rises 65 feet.
29	Southern Pacific Co.	35	....	Capacity, 50,000 gallons a day.
30	?	....	....	Shallow.
31	Coleson, W. M.	25 to 30	....	Two wells. Valley type.
32	Arden	....	8 to 15	
33	Leavall, C. H.	96	....	
34	Peacock	....	8 to 15	
35	Turney and Cockrell	500-|-	....	Dry.
36	Newman	850	....	Dry.
37	Southern Pacific Co.	600	....	Abandoned, water not fit for boiler use.
38	Southern Pacific Co.	41	....	80,000 gallons a day.
40	Southern Pacific Co.	1,120	....	Abandoned, water not fit for boiler use.
41	Fenlay, J. R.	116	96	Two wells. Said to supply 2,500 cattle.
42	Bailey, A. N.	65	....	Dry.
43	Bailey, A. N.	45	....	Dry.
44	Fransal, August	12	....	Feeble spring.
45	Southern Pacific Co.	1,100	....	Abandoned. Little water at 600 feet.
46	Southern Pacific Co.	1,350	....	Abandoned, water unfit for boiler use.
47	Texas and Pacific Ry. Co.	927	905	Abandoned.
48	?	46	....	Dry.
49	Black Mountain Cattle Co.	302	....	Dry.
50	Black Mountain Cattle Co.	110	....	Dry.
51	Black Mountain Cattle Co.	250	....	Dry.
52	Black Mountain Cattle Co.	140	....	Dry.
53	Stephens	....	....	Shallow.
54	Black Mountain Cattle Co.	225	140	
55	Black Mountain Cattle Co.	....	....	Shallow.
56	Coffelt	35	....	
57	?	....	....	Shallow.
58	Ham	35	....	
59	?	....	....	Shallow.
60	Brownfield, W. T.	25 to 30	....	

PARTIAL LIST OF WELLS—*continued.*

(Numbers refer to location on map in pocket.)

No.	Name.	Depth feet.	Depth to water (feet).	Remarks.
61	Russell	48	33	
62	Cottonwood Ranch	10	8	
63	?	48	15	
64	Morrison	10	8	
65	Black Mountain Cattle Co	10	8	
66	Black Mountain Cattle Co	52	32	
67	Texas and Pacific Ry. Co	600		Dry.
68	Texas and Pacific Ry. Co	187		Very little water.
69	Texas and Pacific Ry. Co	300		Dry.
70	Texas and Pacific Ry. Co	70	50	Six wells, capacity 50,000 gallons a day.
71	Millican	22-|-		
72, 73, 74	Bounds	23 to 86		
75	Black Mountain Cattle Co	80	15	
76	Black Monntain Cattle Co	225	200	
77	Patterson	80	15	
78	Abel	20	15	
80	Aultman	25	20	
81	Aultman	130		Dry.
82	Black Mountain Cattle Co	8 to 30	3 to 15	Four wells.
83	Black Mountain Cattle Co	80	20	
84	Black Mountain Cattle Co	90	70	
85	Black Mountain Cattle Co	10	3	
86	Cannon	20	16	
87	Cannon	30		
88	Texas and Pacific Ry. Co	600		Four wells, "u n l i m i t e d amount" of good water.
89	Cannon	60		Dry.
90	Cannon	180		Dry.
91	Cannon	20	16	
92	Black Mountain Cattle Co	225	125 and 225	
93	Black Mountain Cattle Co	110	80	
94	Black Mountain Cattle Co	60	20	
95	Holt	300	280	
96	D Ranch	80	76	Water rises 25 feet and supplies 2,000 cattle.
97	Ussery, J. G			Shallow; good water.
98	Black Mountain Cattle Co	110	80	
99	Black Mountain Cattle Co	225	200	
100	Black Mountain Cattle Co	245		Abandoned.
101	Cannon	160	140	
102	?	200		Abandoned.
103	?	200		Abandoned.
104	?			
105	Medley	212 ?		
106	Medley	265		
107	Texas and Pacific Ry. Co	343		Capacity 40,000 gallons a day.
108	Texas and Pacific Ry. Co	547		Dry.
109	X Ranch	600	260	Abandoned.
110	X Ranch	137		Dry.
111	Marley	?		
112	Marley	150		Dry.
113	Aden	916		Dry.
114	Tinnin	800		Dry.
115	White, D. F	400 ?		Dry.
116	White, D. F	546	260	
117	?	80		Abundant supply, water rises 25 feet.
118	Huling	16	9	
119	Smith, R. W	39	12	
120	Cave Well	?	38	
121	Tinnin	107		Dry.
122	Tinnin	700		Dry.
123	Tinnin	100-|-		Dry.
124	Horse Well		50 ?	
125	Luckett, H. H	70	35	
126	Schilling	45		
127	Tinnin	170		Dry.
128	Tinnin	220		Dry.
129	Tinnin	200		Dry.
130	Marley	300		Dry.
131	Texas and Pacific Ry. Co	325		Dry.
132	Texas and Pacific Ry. Co	80		Dry.
133	X Ranch	170		Dry.
134	Seye	250	199 and 235	

PARTIAL LIST OF WELLS—*continued.*

(Numbers refer to location on map in pocket.)

No.	Name.	Depth feet.	Depth to water (feet).	Remarks.
134a	Sayles	50		
135	Sayles	90		Dry.
136	Sayles	85		Dry.
137	Sayles	34 68	43	
138	Walker Wells	49 and 71	24	
139	Sayles	80 and 100		Three dry wells.
140	Sayles	32 and 88		Little water, pumped dry in four months.
141	Sayles	46 and 92		Dry, little water at first.
142	Earp, Ben	60 and 100		
143	Sulphur Prospect Well	300		Dry; all gypsum.
144	Cooksey, J. E.	60		
145	Kendall	120		Dry.
146	Kendall	103		Dry.
147	Hart	?		
148	Cowan, W.	165	152	Eight gallons an hour, good.
149	Tatum	515		Dry.
150	Tatum	150-|-		4 wells (dry).
151	Texas and Pacific Ry. Co.	400		Dry.
152	Tatum	362		Dry.
153	Seye	?		
154	Cowan	?		
155	Tinnin ?	?		
156	Tinnin, C.	100-|-		Trace of oil.
157	Tinnin, C.	100-|-		
158	Tinnin, C.	100-|-		
159	Tinnin	?		Dry.
160	Tinnin	?		Dry.
161	Tinnin	?		
162	Tinnin, W	?		
163	?		25	
164	?	16	8	
165	Bruce	50 ?		
166	White, J	?		Shallow, bad water.
167	White, J	315		Water horizon at 260; water rises 68 feet.
168	Leatherman, J. D.	36		
169	Cowan, W. D	190	60	
170	Texas and Pacific Ry. Co	400		1,000 gallons a day.
171	?	120	90	
172	Morse, J	120	85	
173	Hoglan	112	100 ?	
174	Texas and Pacific Ry. Co.	832		Artesian well, sulphur water. Capacity 432,000 gallons daily.
175	Leatherman, J. D	20		
176	Coleson	140		
177	White, J	?		Abandoned, quicksand.
178	Tucker	?		Shallow, fresh water.
179	Pope's Well	1,050		Water at 365 feet, rises 70 feet; at 640 feet, rises 390 feet.
180	Robbins	60 ?		
181	Big Philip Well ?	395		Water horizon at 275 feet; water rises 75 feet.
182	Ross	260		Trace of oil at 215 feet.
183	Casey	207		
184	Casey ?	160 ?		
185	Hurd Well ?	400 ?		Water occurs within 20 feet of surface.
186	Texas and Pacific Ry. Co	213		Artesian; water rises above the surface 28 feet. Capacity 85,000 gallons a day.

INDEX.

THE UNIVERSITY OF TEXAS MINERAL SURVEY
WILLIAM B. PHILLIPS
DIRECTOR

SECTION SCALES, HORIZONTAL: 8 MILES = 1 INCH, VERTICAL: 14000 FEET = 1 INCH

RECONNAISSANCE GEOLOGIC MAP AND SECTIONS OF TRANS-PECOS TEXAS NORTH OF THE TEXAS AND PACIFIC RAILWAY

BY G. B. RICHARDSON

— SCALE —

10 0 10 20 30 MILES

CONTOUR INTERVAL 200 FEET

1903