GEOLOGY OF YELLOW HILL QUADRANGLE

BREWSTER COUNTY, TEXAS

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BREWSTER COUNTY, TEXAS

by

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THESIS

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FRONTISPIECE

View east toward xenolith of Boquillas Limestone in stepped portion of Black Ridge sill, west of Black Ridge

PREFACE

Many people have contributed to this thesis. As an aspiring vertebrate paleontologist who found himself with a thesis area that contains only a few small outcrops of Tertiary sedimentary rocks, when more extensive Tertiary deposits and associated Tertiary vertebrate faunas had been hoped for, I especially benefited from the assistance of others.

The members of my thesis committee deserve special mention for their help and guidance. Dr. John A. Wilson suggested the problem, and served as supervisor of the project. I benefited much from his experience and familiarity with areas adjacent to mine. Dr. Stephen E. Clagaugh helped with many matters, and was especially helpful with igneous and contact-metamorphic rocks. He also provided NASA funds available to him for the purchase of enlargements of air photos of the thesis area. Dr. Leon E. Long improved the quality of the writing with his scrupulous editing.

I am extremely grateful to Billy Pat and Sadie McKinney for their untiring assistance and support during the weeks spent in the field, and for providing field accommodations during the summer of 1974. Ron and Shirley Willard, of the Study Butte Store, Study Butte, Texas, were also helpful. Jim and Margaret Stevens assisted me on many occasions in the field. Glenn Hatcher helped with some of the field work, and shared use of a departmental jeep during the summer of 1974.

I thank Dr. Virgil Barnes of the University of Texas Bureau of Economic Geology for providing me with the Bureau's air photo coverage of the thesis area for field mapping. I also thank J. W. Macon of the Bureau for his instruction in, and permission for the use of Bureau projection equipment, and for his counsel regarding transferral of the map to the topographic base. Terlingua Ranch road maps were given to me by Jack North of Terlingua Ranch, and by Urban Engineering, of Corpus Christi, Texas.

Many of the faculty and staff of the Department of Geological Sciences of The University of Texas at Austin gave of their time and assistance during the course of this work. Dr. Fred McDowell instructed

me in basic techniques of sample preparation and mineral separation for potassium-argon dating, and performed the dating of my samples. Dr. Daniel S. Barker was helpful in interpreting igneous rocks, and provided chemical data for sills on Mesa de Anguila and Sierra Aguja. He also provided use of a computer program for obtaining norms from chemical analyses. G. Karl Hoops performed the chemical analyses. Dr. Lynton S. Land performed the oxygen isotope analyses of a chert sample, and helped interpret them. Dr. Keith Young identified fossils collected from the thesis area. Drs. Robert L. Folk and Earle F. McBride helped with their counsel in matters of sedimentary petrography. Discussions with Dr. W. R. Muehlberger regarding structural geology, and with Dr. R. O. Kehle regarding sill emplacement, were also helpful.

The following fellow graduate students deserve thanks for their help. Don Parker offered continual support, instructed me in sample preparation for chemical analysis, and provided norms for rocks analyzed. Steve McLean instructed me in the use of X-ray diffraction equipment. Jack Droddy X-rayed many contact-metamorphic samples, determined their mineralogy, and was helpful in interpreting these rocks. Tom Grimshaw was helpful in matters of base map screening and map reproduction. I benefited from many discussions with officemate Jack Donaho, and with John Bumgardner. Art Busbey and John Johnson, III, the student editor, contributed to my mental health on several occasions.

I gratefully acknowledge the assistance of all these people, but I am solely responsible for any shortcomings of this work.

I would like to thank the Awards Committee and the Geology Foundation of the Department for their continued financial assistance in the form of teaching assistantships, generous field support, and a fellowship.

Finally, I thank my parents, Bob and Gracelyn McCulloh, for whom I feel my deepest gratitude.

This thesis represents a conglomeration of the skills, work and ideas of many people in addition to those of the author; I hope that I have presented the final product as a coherent whole.

This thesis was submitted to the committee in March 1977.

Richard Patrick McCulloh
August 1977

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A B S T R A C T

The Yellow Hill Quadrangle is between the Bofecillos, Davis, and Chisos volcanic centers of Trans-Pecos Texas. Tertiary volcaniclastic deposits occur only as small outliers on downthrown sides of faults. Erosion has removed the thin Tertiary section to expose the 1365 m section of Cretaceous limestones, which are mostly biomicrite (wackestone). Tertiary diabase sills have extensively intruded upper Cretaceous limestone, but intruded the entire interval from the upper Comanchean Buda Limestone to the middle Oligocene Mitchell Mesa Tuff, inclusive. The sills form part of a belt of mafic sills which extends into Mexico as much as 70 km to the southeast.

CONTENTS

TEXT

TABLES

Table

ILLUSTRATIONS

Figure

Plate

INTRODUCTION

The Yellow Hill Quadrangle, though once difficult to enter, has recently been made accessible through the completion of many new subdivision roads. The quadrangle is located in southwest Brewster County, Texas, between 29°22'30" and 29°30'00" north latitude and 103°37'30" and 103°45'00" west longitude (Fig. 1). The approximately 170 sq km area contains no towns or highways, and access is via county and ranch roads, and jeep trails.

Access to the southeastern part of the quadrangle is via South County Road. Access to the east flank of the Solitario, or Blue Range, in the western part of the area is via Solitario-Sawmill Road. Both of these roads extend north of Highway 170. The northeast part of the area is accessible via North County and Hen Egg Roads, the latter of which extends west from Highway 118. Trails and smaller, less improved roads lead to other places (Plate II).

Locations are given according to the scheme shown in Fig. 2, with numbers referring to spot elevations shown on the topographic base (Plate I). Thus, "Hill 3092 (EC)" refers to the hill, in the east-central ninth of the quadrangle, whose top is at 3092 ft elevation.

Climate and Vegetation

The area is characterized by a semi-arid climate with low rainfall (mean annual 37 cm) and sparse vegetation.

Plants include the ubiquitous lechuguilla (*Agave lecheguilla*), which is most abundant on high, flat surfaces such as sill-capped mesas. Greasewood (*Larrea divaricata*) grows abundantly on low flat terraces and is accompanied in some places by abundant huisache (*Acacia farnesiana*). False agave (*Hechtia scariosa*), candelilla (*Euphorbia antisyphilitica*), and the hairy resurrection plant (*Selaginella pilifera*) are abundant on Comanchean limestones of the Blue Range and Terlingua-Solitario anticline. Mesquite (*Prosopis juliflora*) and catclaw (*Mimosa biuncifera*) are abundant along intermittent streams. Other plants in the area include ocotillo (*Fouquieria splendens*), sotol (*Dasylirion leiophyllum*), guayacan

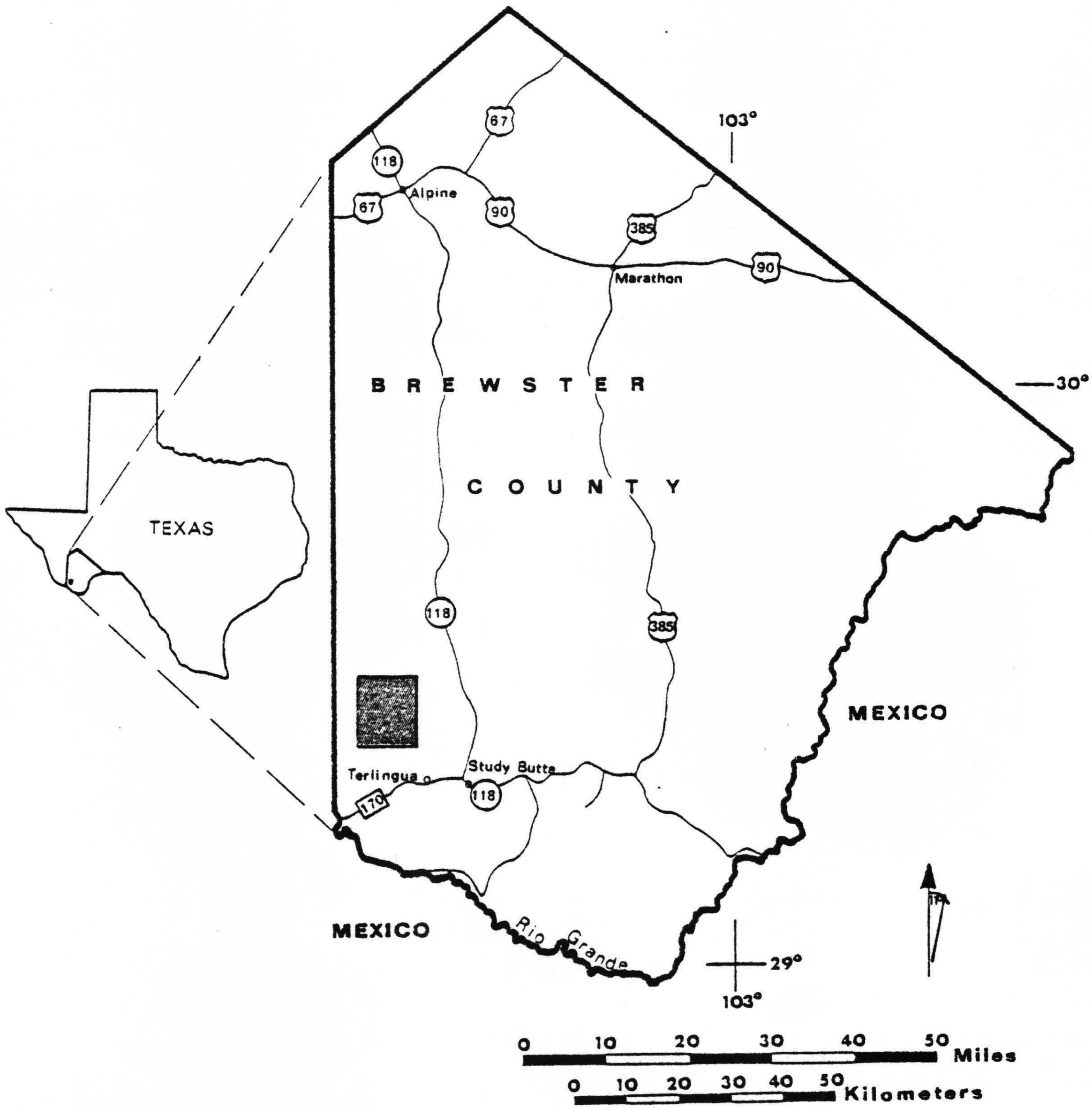


Fig. 1. Location of Yellow Hill Quadrangle.

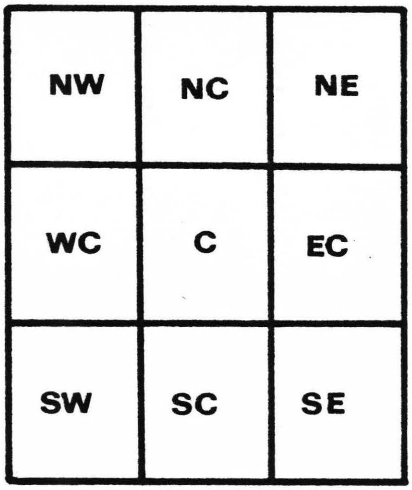


Fig. 2. Location scheme used in text.

(Porlieria angustifolia), mormon tea (Ephedra), tasajillo (Opuntia leptocaulis), Spanish Dagger and soaptree yucca (Yucca), cholla (Opuntia imbricata), allthorn (Koeberlinia spinosa), leatherstem (Jatropha dioca var. graminea), foothill basketgrass (Nolina erumpens), and different types of prickly pear (Opuntia). Several types of short grasses grow in clumps. Among the small cacti are button cactus (Epithelantha micromeris), rainbow cactus (Echinocereus dasyacanthus), Graham dog-cactus (Opuntia grahamii), livingrock cactus (Ariocarpus fissuratus), eagle's-claw cactus (Echinocactus horizonthalonius), and others. Pitaya (Echinocereus stramineus) and purple pitaya (Echinocereus dubius) cacti grow in hemisperical clusters. Small flowers, which appear along draws in the spring, include spike phacelia (Phacelia congesta), large flower nemophila (Nemophila phacelioides), margined perityle (Perityle vaseyi), Big Bend bluebonnet (Lupinus havardii), and bracted paintbrush (Castilleja latebracteata). Desert baileya (Baileya multiradiata) is also common during the summer, and yellow-trumpet-flower (Tecoma staus), limoncillo (Pectis angustifolia), and Parry ruellia? (Ruellia parryi) grow throughout the summer on weathered diabase detritus.

Land Use

The area has been sparsely settled in the past with ranching providing the main source of income, although some prospecting has been done on the eastern flank of the Solitario. The extreme north-central part of the area is on the Agua Fria Ranch, which raises cattle and until recently, goats. The rest comprises a part of the Terlingua Ranch, a land-sale operation. The Terlingua Ranch has been subdivided into approximately 5,000 10-acre plots, over 95 percent of which had already been sold to private owners by the summer of 1974. New unimproved roads have been pushed through most of the Yellow Hill Quadrangle by Terlingua Ranch owners to reach the many 10-acre plots (Plate II). Very few of the plots have actually been settled to date; less than one percent have buildings on them.

Geologic Setting

Most of the Yellow Hill Quadrangle is underlain by Cretaceous limestone. Tertiary diabase sills, which intrude the limestone, cover most of the rest of the area. Cretaceous shale is locally extensive where it has been faulted down against limestone. Tertiary sandstone, tuff, and ash-flow tuff are found only in the northernmost part of the area, where they and Cretaceous shale are also intruded by Tertiary diabase sills. Small Tertiary intrusive plugs and chert breccias of probable hydrothermal origin occur in some of the Cretaceous limestone.

Comanchean rocks are exposed on the eastern flank of the Solitario and on the Terlingua-Solitario anticline in the western and southwestern parts of the area; they are also exposed along the Yellow Hill fault in the central part of the area and in the bed of Terlingua Creek in the northeast. Gulfian rocks crop out over much of the eastern three-fourths of the area except on the Terlingua-Solitario anticline in the southwest. The Tertiary diabase sills occur in a northwest-trending, structurally controlled belt in the northeastern half of the area.

The quadrangle lies at the western edge of Udden's (1907) Sunken Block, which is bounded by Mesa de Anguila on the southwest and the Sierra del Carmen on the northeast (Moon, 1953). Structural features in the area trend predominantly northwest. The area is located between the Davis Mountains to the north, the Chisos Mountains to the southeast, and the Bofecillos Mountains to the southwest, which comprise three of the major volcanic centers in the Big Bend region. Volcanic deposits which originated from these centers thin toward the area from each direction.

Faults trend northwest, with the exception of some on the Terlingua-Solitario anticline which trend northeast. Faults cut all units mapped except Quaternary alluvium. The Solitario is a dome formed by igneous, probably laccolithic, intrusion (Baker, 1935; Lonsdale, 1940; Herrin, 1958; Corry, 1972). Faults and joints give the area a distinct northwest grain which is reflected in the topography and drainage.

Previous Work

Fig. 3 shows the location of previous work done in the southern Big Bend area. The Yellow Hill Quadrangle had not previously been mapped in detail, but was included in an area mapped in much broader scale by Lonsdale (1940). Lonsdale studied only the igneous rocks. Yates and Thompson (1959) mapped the Terlingua Quicksilver district to the south of the Yellow Hill Quadrangle. Sellards and others (1931, 1933) were the first to prepare more than a reconnaissance map of the Solitario dome. Herrin (1958) made the first detailed map of the Solitario, and Corry (1972) modified this map and incorporated it into his map of the Solitario 7½-minute Quadrangle which adjoins the Yellow Hill Quadrangle on the west. McKnight (1970) mapped the Bofecillos Mountains area which adjoins the Solitario on the southwest. Moon (1953) mapped the Agua Fria Quadrangle to the north and northeast. The Pruett Formation (Tertiary) and its vertebrate faunas in this quadrangle have been studied by Stevens *et al*. (in preparation), and by Wilson (1974, 1977). Hatcher (in preparation) mapped an area within the southwestern portion of the Agua Fria Quadrangle, to the north of the Yellow Hill Quadrangle. The Tascotal Mesa Quadrangle to the northwest was mapped by Erickson (1953). Goldich and Elms (1949) first described, named, and mapped the Buck Hill Volcanic Group, named after the Buck Hill Quadrangle, which adjoins the

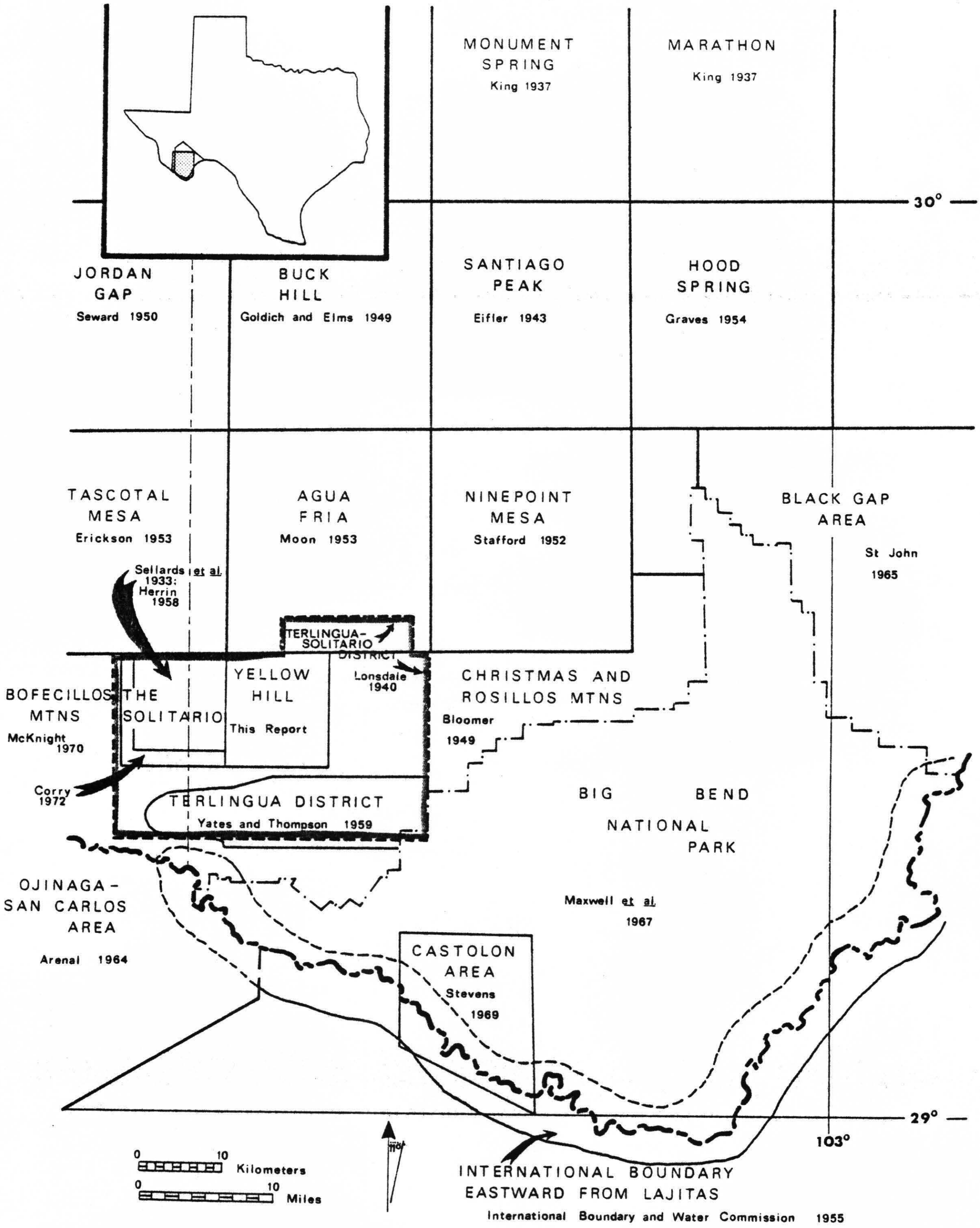


Fig. 3. Index to areas mapped, Big Bend Region, Texas. After McKnight (1968).

Agua Fria Quadrangle on the east. To the southeast of all the above areas lies Big Bend National Park, mapped by Maxwell and others (1967).

Purpose and Methods of Investigation

The purpose of this study was to prepare a geologic map of the Yellow Hill Quadrangle, to describe its geology, and to search for vertebrate fossil localities in the area. I spent approximately ten weeks in the field during the summer of 1974, and additionally, one week during March 1975 and one week in May 1975. Information was recorded on 9 inch x 9 inch air photographs at a scale of approximately 1:60,000. This information was transferred to a mylar positive of the U.S.G.S. topographic base map of the area, which was made from a film negative of the base obtained from the U.S.G.S. The final geologic map was reproduced at a scale of 1:24,000, the scale of the topographic base.

New Terlingua Ranch access roads were plotted (Plate II) from maps prepared by Urban Engineering (Corpus Christi, Texas) of proposed roads. These provisional maps were prepared before the roads were constructed, and they do not everywhere depict the real roads.

Samples were collected from all units mapped, and thin sections of samples representative of most units were cut. Chemical analyses and K-Ar ages were determined for two diabase sill rocks. Sections were measured with Brunton compass and jacob staff. One biostratigraphic zone was treated as a mappable unit.

Undifferentiated stream alluvium is the only mapped Quaternary unit. Quaternary terrace gravels in the area are thin and restricted. The most extensive of these gravels occurs as a calichified crust, generally less than ½ m thick, which forms a thin veneer over the Boquillas and Pen Formations. This "caprock" consists of pebbles, cobbles, and boulders of Boquillas flaggy limestone, and some diabase fragments, all cemented by caliche. I could locate contacts between underlying bedrock units beneath the more extensive areas of gravel by checking draws and gullies. Though some of these contacts are uncertain, I have chosen to make the map a bedrock map. Consequently, an inferred underlying Boquillas Pen contact is mapped rather than the thin Quaternary gravel cover.

PHYSIOGRAPHY

Semi-arid climate and sparse vegetation make structure and lithology the principal controls on physiography in the Yellow Hill Quadrangle and surrounding areas. The topography is rough but varies from blocky where faulted, to smooth on dip slopes of limestones and diabase sills, to jagged where extensively dissected, especially on incompetent shaley and marly outcrops.

Physiographic Expression of Intrusive Rocks

Flat-topped mesas occur where resistant, Tertiary diabase sills have been uncovered by erosion. These mesas may have nearly straight edges in plan view where sills are adjacent to faults; otherwise they are irregular because of stream dissection. In the southeast part of the area, small diabase plugs and diabase sill outliers cap conical hills of Boquillas Limestone, as at Pink's Peak, Hill 3308 (SE), Hill 3664 (SC) and Hill 3538 (SE) (Plate I). Smaller diabase plugs, which occur in an approximate northwest trend through the area, stick up as small knobs above Boquillas Limestone and Pen Shale. Diabase dikes weather out in only slight relief because they are short and thin.

Plugs of other intrusive igneous rock types may appear as knobs or may have very little topographic expression. One roughly circular outcrop of a rhyolitic, rock fragment-rich rock interpreted to be a vent on the northeast flank of the Solitario is expressed as an amphitheater. The margins of the body are more resistant to erosion than the interior and weather into reddish crags. Some red and white chert breccias occur as small plug-like knobs which project above the Buda Limestone on the eastern flank of the Solitario.

Physiographic Expression of Sedimentary and Volcanic Rocks

Resistant lower Cretaceous limestones, especially the Santa Elena, form dip slopes in the western and southwestern parts of the area. These are most extensive on the eastern flank of the Solitario, where they form the backs of stream-dissected cuestas. On the Terlingua-

Solitario anticline an extensive dip-slope surface of the Santa Elena is displaced by a network of intersecting normal faults (Fig. 4). Outliers of Buda Limestone and Del Rio Clay occur on downfaulted blocks of Santa Elena Limestone on this anticline. Downfaulting has made synclines of two Buda outliers, Hill 3735 (SC) and Hill 3850 (SW), which stand out in relief (Plate I). Less-resistant, lower Cretaceous marls and shales of the Telephone Canyon, Sue Peaks, and Del Rio Formations, form slopes beneath the limestones on the eastern flank of the Solitario and the northeastern flank of the Terlingua-Solitario anticline.

Fig. 4. View southeast across block-faulted northeast flank of Terlingua-Solitario anticline, where faults show as displacements of dissected dip slope surface of Santa Elena Limestone. Northeast-trending grabens and horsts intersect northwest-trending ones. Small Del Rio Clay outlier is preserved on downdropped block, left center.
Figs. 24 and 25 include same area.

Upper Cretaceous Boquillas flaggy limestone which is exposed over much of the eastern three-fourths of the area is extensively dissected by intermittent streams. The alternation of beds varying in resistance to erosion has resulted in diverse topographic types, including jagged or badlands-like, low hills and swales, low cuestas, and flat areas. Yellow Hill consists of Boquillas Limestone which stands above flat-lying Boquillas and Buda surroundings; it is probably the remnant of a once diabase-capped mesa. An outcrop of contact-metamorphosed Boquillas, thought to overlie a concealed trap-door intrusive, forms an anomalous dome with elliptical shape. Because of alteration of the alternating hard and soft layers, and jointing, it weathers into forms resembling stacks and chimneys.

The shaley upper Cretaceous Pen Formation, where areally extensive, weathers into either low mounds or rugged badlands, with a few knife-edge ridges where small divides are being destroyed. The Pen also forms slopes with the overlying sandstones of the Tertiary Pruett Formation in the northern part of the area, beneath more resistant diabase or Mitchell Mesa Rhyolite.

Effect of Structure on Physiography

Faulting has created diverse topographic forms. Graben and horst terranes occur where Boquillas and Pen have been juxtaposed by faults, forming resequent fault line scarps which stand out boldly. On the Terlingua-Solitario anticline, northwest-trending grabens and horsts are cross-cut by northeast-trending ones, creating a field of jostled, rectangular fault blocks strikingly displayed on the Santa Elena dip slope (Fig. 4). The Yellow Hill Fault is expressed by a northeast-facing cuesta of Buda Limestone overlying Del Rio Clay on the upthrown side of the fault. This cuesta outlines a resequent fault line scarp against the lower, Boquillas Limestone on the downthrown side. Rectangular joint patterns etch out prominently on dip slopes of Santa Elena Limestone. Some cuestas of Boquillas have saw-toothed edges formed by intersecting joint sets. Folds in the area stand out in bold relief regardless of size, because of surrounding faults and differential weathering.

Drainage

The Yellow Hill Quadrangle is in the drainage basin of the middle Rio Grande. The drainage is controlled by structure, is predominantly dendritic, and has an overall southeasterly direction. On the east flank of the Solitario the drainage pattern is radial. On the Terlingua-Solitario anticline, because of the gridwork of intersecting faults, the drainage approximates a rectangular northeast-northwest pattern.

All streams are intermittent. The largest, Terlingua Creek, is a south-southeast flowing tributary of the Rio Grande. It is joined by Alamo de Cesario Creek a few kilometers to the north of the area, and is eventually fed by all other streams in the area. Immediately after receiving heavy rains, Terlingua Creek runs high and hard through its twisting canyon, and may continue to run for several days. The other major stream in the area is Saltgrass Draw, which flows southeasterly and joins Terlingua Creek to the east.

Elevation

The overall slope is to the southeast. A maximum elevation of 5,006 ft (1,526 m) is located in the west-central part of the area on the east rim of the Solitario. A minimum elevation of less than 2,840 ft (866 m) is reached in the southeast part of the area east of Pink's Peak, and also in Saltgrass Draw.

Surficial Deposits

No well-developed soils were observed; cover consists of talus and terrace gravel. Talus consists of angular, joint-bounded blocks of diabase, and angular rubble of weathered Boquillas limestone fragments held together by finer material and caliche, like the terrace gravel previously mentioned. The thin terrace gravel covers the Boquillas and Pen Formations at elevations of 3,000-3,200 ft on terrace remnants in the east-central and southeast parts of the area (Plate I). A few small outliers of terrace gravel deposits occur in the southeastern corner of the quadrangle, in the vicinity of Pink's Peak. These gravels contain much locally derived basaltic and diabasic material.

The only soil-like deposit is several centimeter-deep, brown, sandy decomposed diabase developed by in situ weathering in some small areas along drainages on the southernmost diabase sill. This along with numerous joints filled by caliche indicate that this is the only sill that has experienced significant weathering.

STRATIGRAPHY AND PETROGRAPHY

General Statement

The maximum total thickness of the sedimentary and volcanic rocks exposed in the area is about 1,415 m. The distribution of formations is shown on the geologic map (Plate I).

Stratigraphic nomenclature used in this report for Cretaceous formations is that established by Maxwell et al. (1967). Lower Cretaceous units consist of limestone which is predominantly biomicrite (wackestone); the thin Del Rio Clay is an exception. These units are exposed in the western and southern parts of the map area, on the east flank of the Solitario and on the Terlingua-Solitario anticline, and locally along Terlingua Creek (NE) and the Yellow Hill fault. In the Yellow Hill Quadrangle, the Comanchean section is approximately 760 m thick.

Meager fossil data do not permit faunal correlation of lower Cretaceous units with the same or equivalent units in other areas, so that lithology and position in the sequence are the principal criteria for correlation. Corry (1972, Table 7) shows partial faunal correlation for the lower Cretaceous of the Solitario with that of Big Bend National Park (Maxwell et al., 1967) and northern Coahuila (Smith, 1970).

Upper Cretaceous formations consist of limestone composed of clayey foraminifer biomicrite (wackestone), and of calcitic foraminiferal clay-shale. These units are exposed over most of the northeastern three-fourths of the area. The estimated thickness of the Gulfian section is 600 m.

Tertiary rocks consist of sandstone, conglomerate, tuff with minor caliche limestone nodules, and welded ash-flow tuff. Outcrops are small and lie on downthrown sides of faults, in the extreme northern part of the quadrangle. The Tertiary section is markedly thin compared to that of surrounding areas, because of Tertiary non-deposition and perhaps erosion. The thickness of Tertiary strata in the quadrangle is estimated to be 20-50 m.

Alluvium in stream channels consists of silt, sand, and limestone pebbles, cobbles, and boulders. It is thickest in the canyons which drain the east flank of the Solitario, where it is probably up to 15 m thick. In those canyons cut into the rim of the Solitario, the alluvium consists almost entirely of Comanchean limestone boulders.

Thin terrace gravel covers areas in the central part of the area, and in small parts of the southwestern and southeastern parts of the area. The gravel is generally less than ½ m thick, and consists of caliche-cemented Gulfian limestone fragments.

Strata in the map area generally have dips of less than 30°. Those strata having greatest dips are Comanchean limestones on the eastern rim of the Solitario, and Gulfian limestones wherever they are faulted, domed, or intruded.

A generalized composite columnar section is shown in Fig. 5. A more detailed stratigraphic section of Lower Cretaceous formations, measured across the rim of the Solitario, is Fig. 6. Table 1 gives time-stratigraphic and rock-stratigraphic classification of units.

The petrographic terminology used in this report is that of Folk (1976, 1974a) and Dunham (1962).

Cretaceous System

Comanchean Series

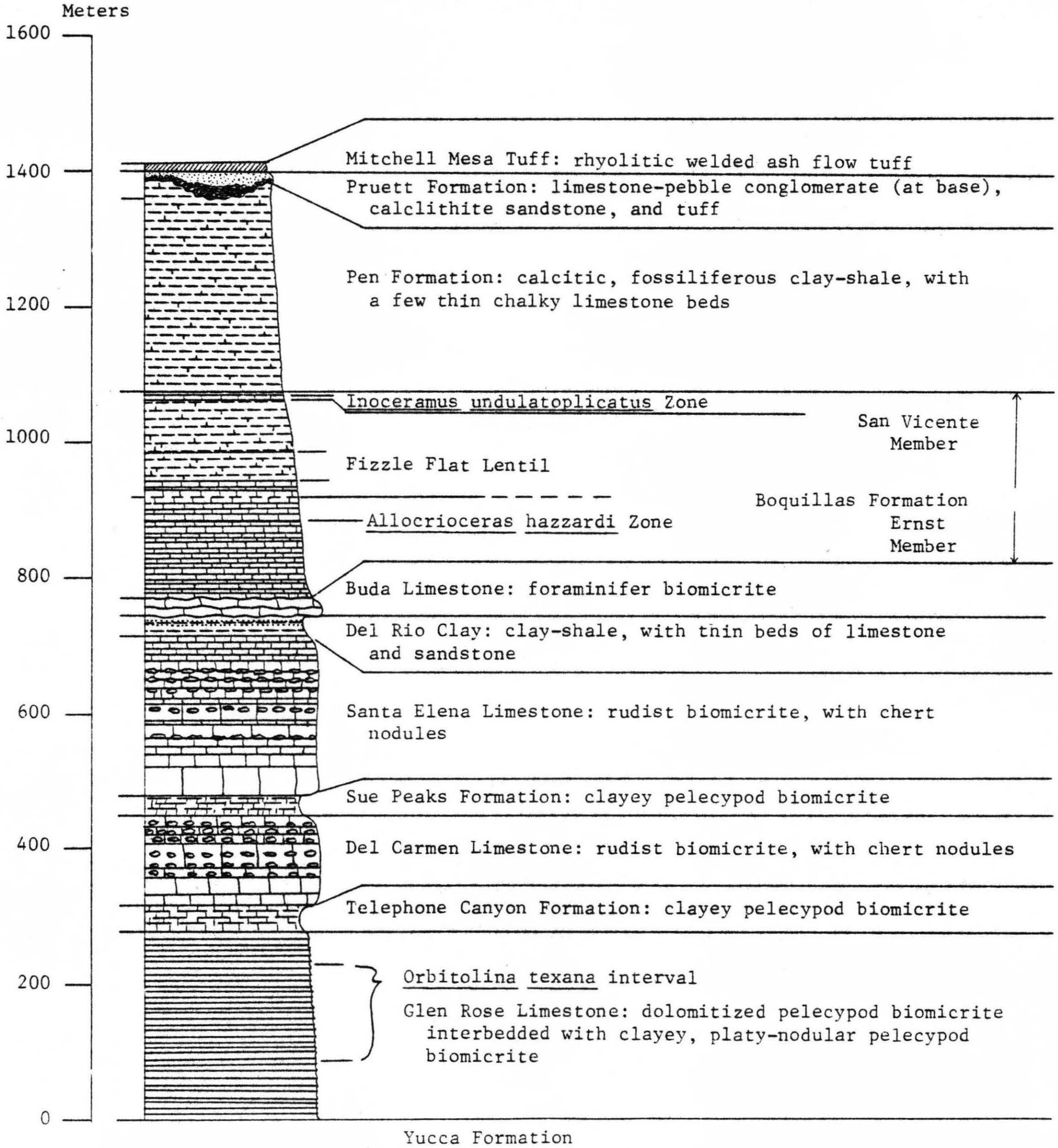
TRINITY GROUP

Glen Rose Limestone

Name and type section--R. T. Hill (1891) named the Glen Rose from rocks exposed along the Paluxy River near Glen Rose in Somervell County, Texas. Here the formation has a characteristic "stairstep" appearance because it consists of differentially weathered, alternating beds of resistant limestone and less-resistant marl.

Distribution, thickness and lithology--The only exposures of the Glen Rose in the Yellow Hill Quadrangle are along the inner rim of the Solitario (Plate I). Here the formation shows the stairstep topography with

Fig. 5. Generalized Stratigraphy and Petrography of Yellow Hill Quadrangle



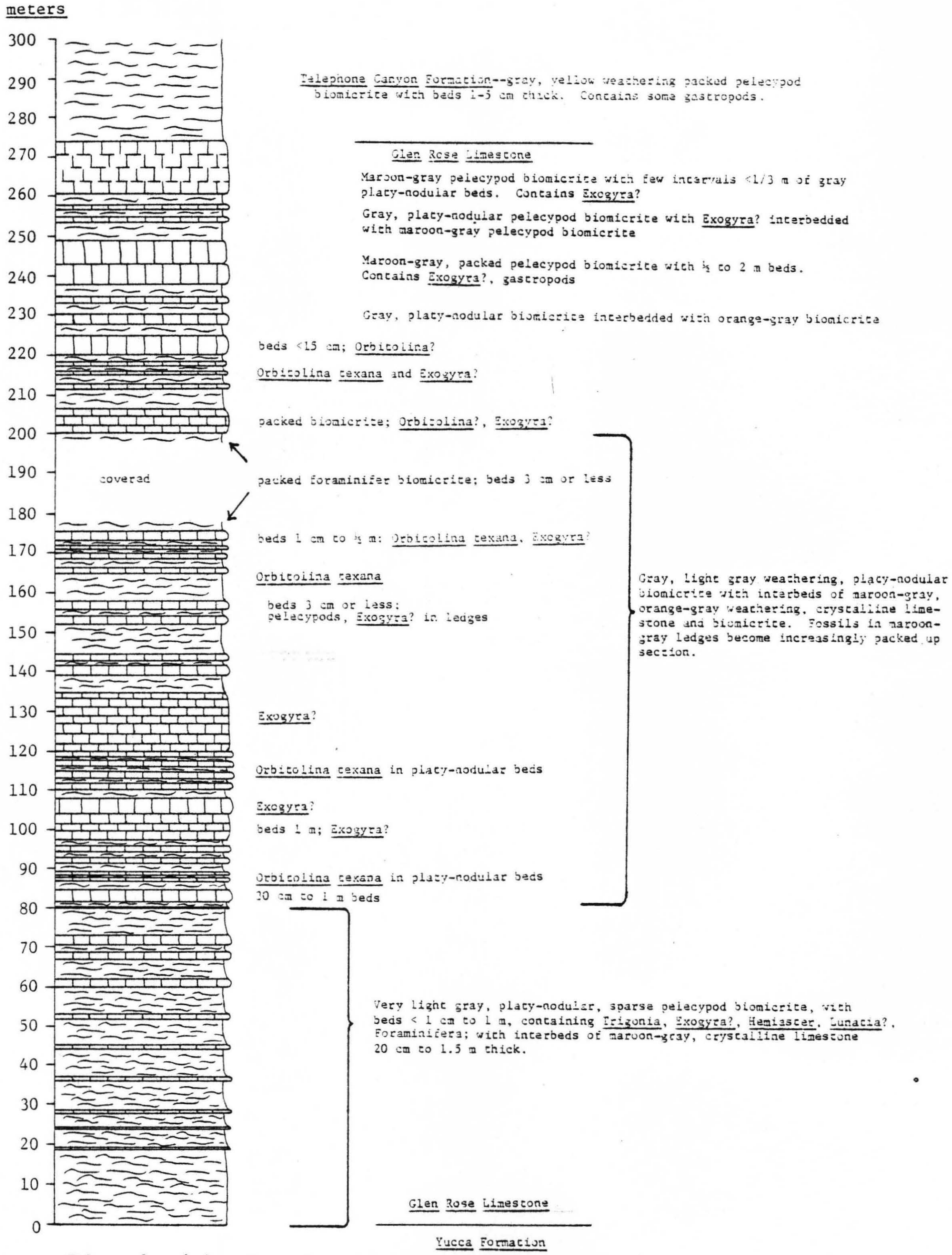


Fig. 6. (a) Section measured across rim of Solitario.

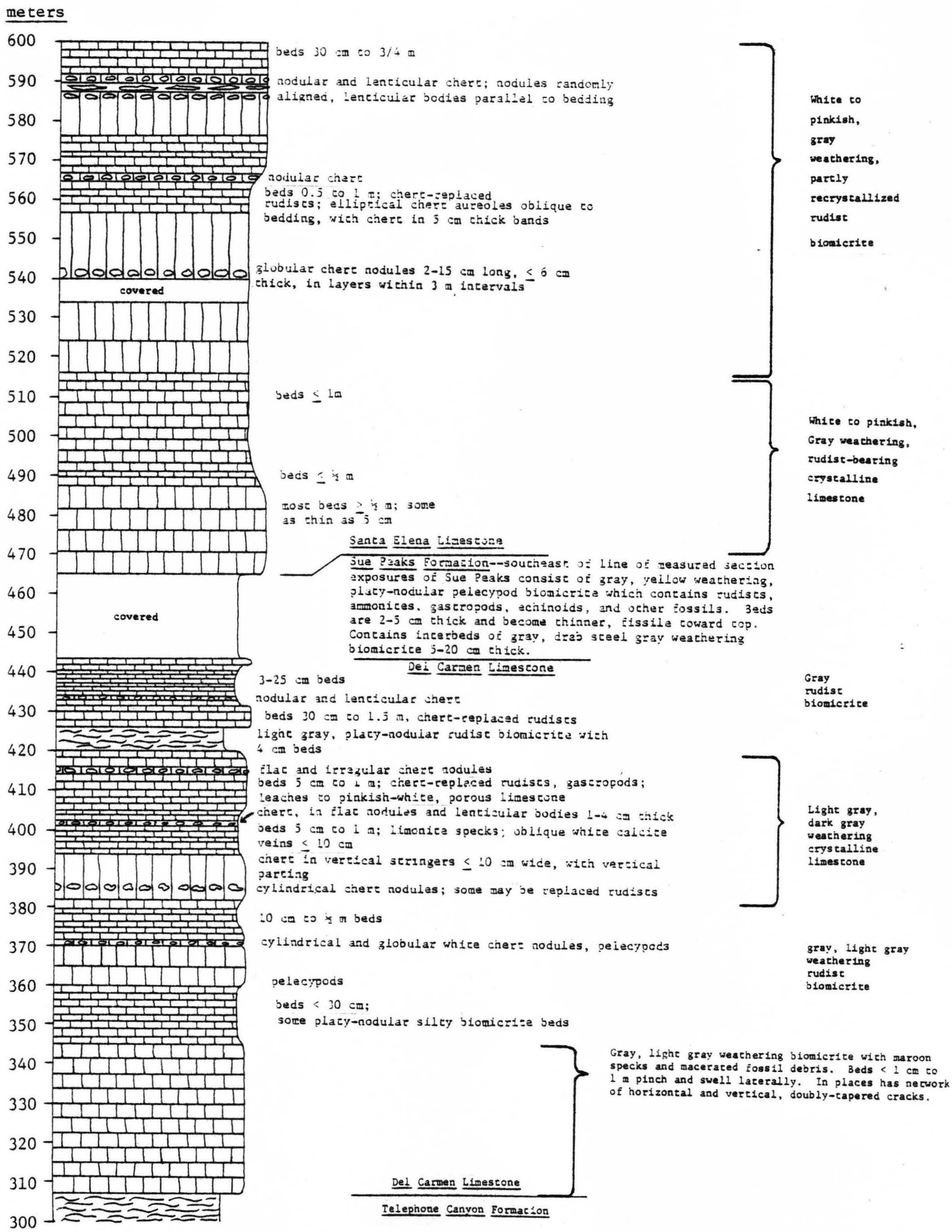


Fig. 6. (a) (continued).

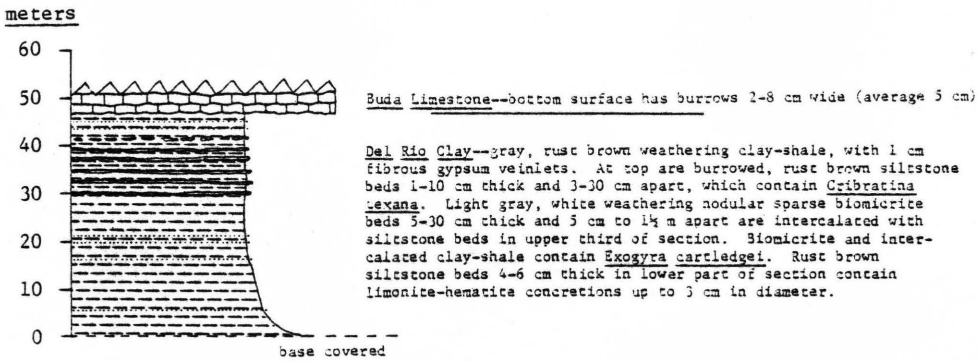


Fig. 6. (b) Section measured ½ km east of Hill 3740 (SC).

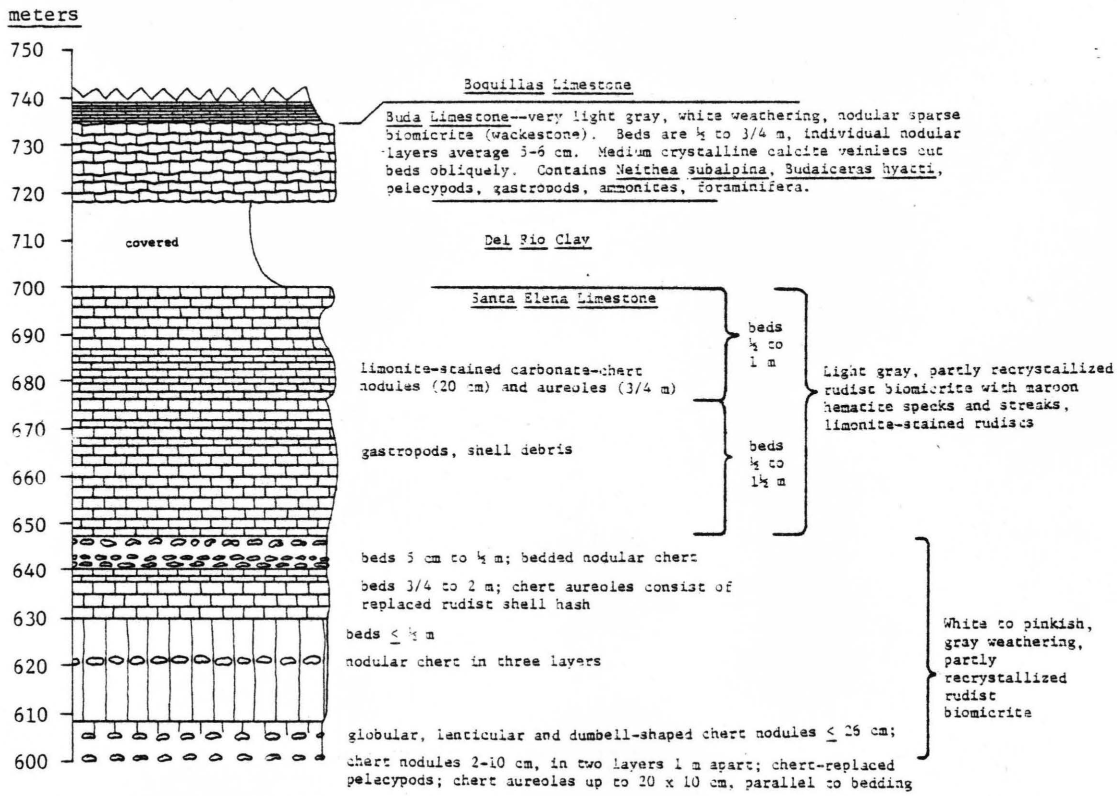


Fig. 6. (a) (continued).

Table 1. Generalized stratigraphic classification in Yellow Hill Quadrangle.

TIME-STRATIGRAPHIC UNITS				ROCK-STRATIGRAPHIC UNITS		
SYSTEM	SERIES	STAGE		GROUP	FORMATION	THICK-NESS (m)
QUATERNARY	Pleistocene ? to Holocene				Alluvium	≤15*
TERTIARY	Oligo-cene	CHADRONIAN		BUCK HILL	Mitchell Mesa Tuff	10*
TERTIARY	Eocene	UINTAN		BUCK HILL	Pruett Formation	10-40*
CRETACEOUS	GULFIAN	SANTONIAN		TERLINGUA	Pen Formation	300*
CRETACEOUS	GULFIAN	CONIACIAN / TURONIAN		TERLINGUA	Boquillas Formation	300*
CRETACEOUS	COMANCHEAN	CENOMANIAN		WASHITA	Buda Limestone	18
CRETACEOUS	COMANCHEAN	CENOMANIAN		WASHITA	Del Rio Clay	18 to >40
CRETACEOUS	COMANCHEAN	ALBIAN	Upper	WASHITA	Santa Elena Limestone	236
CRETACEOUS	COMANCHEAN	ALBIAN	Middle	WASHITA	Sue Peaks Formation	22
CRETACEOUS	COMANCHEAN	ALBIAN	Middle	FREDERICKS-BURG	Del Carmen Limestone	136
CRETACEOUS	COMANCHEAN	ALBIAN	Middle	FREDERICKS-BURG	Telephone Canyon Formation	33
CRETACEOUS	COMANCHEAN	ALBIAN	Middle		Maxon Sandstone	Absent
CRETACEOUS	COMANCHEAN	ALBIAN	Lower	TRINITY	Glen Rose Limestone	274

alternating hard and soft limestone beds. The base of the Glen Rose lies outside the quadrangle to the west, in the Solitario Quadrangle. Corry (1972) separated the Glen Rose in the Solitario from an underlying unit which he identified as the Yucca Formation, because of its greater terrigenous content and greater dolomitization. The Yucca overlies the basal Cretaceous Shutup conglomerate, which overlies with angular unconformity the Paleozoic section of the interior of the Solitario. The Shutup Conglomerate markes the inner edge of the rim of the Solitario.

In the Yellow Hill Quadrangle, the Glen Rose Limestone consists of about 274 m of alternating dark maroon-gray limestone ledges and gray to light gray to yellowish, platy-nodular to fissile "marl." Along much of their outcrop, the resistant ledges have been recrystallized, probably during outcrop weathering, and are finely to coarsely crystalline limestone. These ledges are massive or have beds greater than 20 cm thick, but some are platy like the lighter colored marly beds.

Petrography--The resistant limestone ledges consist of dolomitized, packed pelecypod or foraminifer biomicrite. The micrite matrix contains minor quartz silt and very fine sand. Cavities are filled with finely to very coarsely crystalline sparry calcite. There are three varieties of dolomite:

(1) medium crystalline dolomite, which lines spar-filled cavities, seams, and some fossil molds
(2) aphanocrystalline replacement dolomite, which has replaced parts of the micrite matrix
(3) sparse, single rhombs or ghosts of rhombs, finely to medium crystalline, in micrite matrix, that could represent primary dolomite.

The first two varieties of dolomite have associated with them a limonite strain, while the micrite matrix contains clusters of aphanocrystalline hematite crystals, indicating along with textural relations a non-primary origin of these dolomite types, probably associated with migrating subsurface fluids. Some of the medium crystalline dolomite shows limonite zoning.

In addition to pelecypods and Foraminifera, the ledges contain abundant quantities of an allochem type that can resemble algal coats, or lumpy intraclasts grading into non-uniform-sized "pellets," which grade into smaller clots within the micrite matrix. Allochems are predominantly packed.

Some of the pelecypods have become spar-filled molds, perhaps a result of neomorphism, but the absence of preserved fibrous structure makes solution-cavity fill another possibility. On weathered outcrops these fossils show partial replacement by silica. The micrite matrix contains some rosettes of length-slow chalcedony, most of which are less than 0.2 mm in diameter.

The platy-nodular "marl" is clayey, sparse pelecypod or foraminifer biomicrite (wackestone) with minor quartz silt and very fine sand. Sparry calcite fills foraminifer chambers and other cavities. The micrite matrix contains isolated patches of either finely to medium crystalline pseudospar or neomorphosed shell fragments. Some shell fragments have minor amounts of chert in cavities. Minor amounts of megaquartz occur as cylindrical bodies 0.02 mm in diameter and may be filled borings.

In both limestone types, clusters of aphanocrystalline hematite up to 0.5 mm are concentrated in cracks and at the edges of echinoderm and pelecypod fragments. The resistant ledges have limonite associated with dolomite, while the "marl" has limonite localized along microstylolites. This indicates that meteoric diagenesis was responsible for the non-depositional textural features noted, though sparry calcite and dolomite could have formed in subsurface diagenetic realms (Folk, 1974a).

Fossils--The following fossils were identified from the Glen Rose:

Trigonia sp.
Exogyra sp. ?
Lunatia sp. ?
Hemiaster sp.
Orbitolina texana Römer
Dictyoconus sp.

Unidentified fossils include bryozoans, ostracods, gastropods, a crinoid columnal, a possible green alga, a possible rudist, and many Foraminifera.

Orbitolina texana and Exogyra sp. ? are the most abundant fossils. Orbitolina is found mostly in marly beds within the interval 85-215 m above the base of the Glen Rose. Exogyra sp. ? is abundant in the ledges but no specimens were found which had weathered out. In beds lacking Orbitolina, the most abundant Foraminifera are miliolids, Dictyoconus sp. and types resembling globigerinids. Other Foraminifera include types that are uniserial, uniserial-biserial, and biserial (cf. Textularia sp.).

Adkins (1933) identified some fossils collected from the Glen Rose in the Solitario, and Herrin (1958) gives the most complete faunal list for this unit.

Correlation--The above fossils alone are insufficient for precise correlation, but together with lithostratigraphic correlation of the sequence of superjacent formations permit correlation with the Glen Rose described by Maxwell et al. (1967) in Big Bend National Park, less than 20 km away. The thickness in the Yellow Hill Quadrangle (274 m) is much greater than that given by these authors for the Park (600 ft = 183 m).

Depositional Environment--The lithology and fossils of the Glen Rose support the interpretation of Smith (1970), who concluded that the formation was deposited in a shallow marine environment subject to periodic influxes of terrigenous fines which produced the marly beds. The alternation of beds of clayey, platy-nodular limestone and dolomitized limestone is like the central Texas Glen Rose sequence, which has been interpreted to consist of subtidal and supratidal deposits, respectively (Dawe, 1967; Rice, 1968). The texture, structures, and fossils are consistent with this interpretation, though almost all the dolomite in the resistant beds cannot be called "supratidal dolomite." If the dolomite was originally "supratidal," it was remobilized and redeposited as replacement dolomite after burial.

FREDERICKSBURG GROUP

Maxon Sandstone

The Maxon Sandstone is not present in the Yellow Hill Quadrangle. P. B. King (1930) named the formation from exposures at Maxon Station at the eastern edge of the Marathon Basin. It has also been reported from the Santiago Peak Quadrangle (Eifler, 1943) and the Hood Spring Quadrangle (Graves, 1954). McAnulty (1955) described possible Maxon from the Catedral Mountain Quadrangle. Maxwell et al. (1967) report that it is exposed about 1½ mi (2.4 km) southeast of Persimmon Gap (Big Bed Park) and that, while it is not recognizable in the Park, more calcareous facies equivalents may be present above the Glen Rose. This plus the absence of the Maxon in the Yellow Hill Quadrangle indicate that the outcrop southeast of Persimmon Gap is probably close to the southern limit of the unit caused by both southward thinning (Graves, 1954) and southward facies change (King, 1937; Eifler, 1943; Graves, 1954; Maxwell et al., 1967). According to Smith (1970), the Maxon Sandstone was deposited in a southward regression from the Marathon region when this region was uplifted at the end of Glen Rose deposition.

Telephone Canyon Formation

Name and type section--Maxwell et al. (1967) named the Telephone Canyon from exposures in Telephone Canyon along Heath Creek in the Sierra del Caballo Muerto of the Sierra del Carmen. Here the formation is thin-bedded nodular limestone and marl which forms a slope between the Glen Rose below, and the cliff-forming Del Carmen Limestone above. Maxwell et al. found the average thickness of the Telephone Canyon to be 75 ft (22.5 m) in Big Bend National Park.

Distribution, thickness, and lithology--In the Yellow Hill Quadrangle, the Telephone Canyon is exposed only along the inner rim of the Solitario. Here, as at the type locality, it weathers to form a slope between the Glen Rose and Del Carmen. The formation lies conformably on the Glen

Rose Limestone, and consists of about 33 m of gray to yellow, clayey platy-nodular pelecypod biomicrite (packstone-wackestone). Beds are 1-5 cm thick.

Fossils and correlation--A few species of unidentified pelecypods and gastropods were collected from the Telephone Canyon. Its lithology and position in the stratigraphic sequence are the basis for correlation with the Telephone Canyon Formation in Big Bend National Park.

Regional features and depositional environment--Smith (1970) traced the Telephone Canyon Formation to the southeast from the type locality into Mexico, where, along the southern Sierra del Carmen, it changes facies to become a part of the Devils River Formation. He gives the average thickness of the Telephone Canyon as 130 ft (39 m) in northern Coahuila, which is about twice that in the Park (Maxwell *et al.*, 1967). The lithology Smith described as consisting of nodular, marly lime wackestones separated by *Gryphaea* packstones (interpreted as oyster biostromes) and shell fragment wackestones, containing less clay toward the southeastern limit. He concluded that the Telephone Canyon was deposited in a shallow sea which received fine terrigenous clastic material from the Marathon Uplift, and that inundation of this source ended Telephone Canyon deposition.

Del Carmen Limestone

Name and type section--Maxwell *et al.* (1967) named the Del Carmen from exposures in fault blocks of the Sierra del Carmen. Here it is massive, gray, "fine- to medium-crystalline limestone" containing nodular and lenticular chert, varying amounts of rudists and some "marly layers." They found the Del Carmen to be 103-107 m (338-350 ft) thick at measured section localities in the eastern part of Big Bend National Park, and 142 m (465 ft) thick in Santa Elena Canyon to the west.

Distribution, thickness, and lithology--In the Yellow Hill Quadrangle, the Del Carmen is exposed only within the rim of the Solitario, but it is a major part of this feature. The upper and lower parts of the formation have beds that range from a few centimeters to 1-2 m, and vary in thickness laterally. The middle part of the formation contains several massive ledges up to 12 m thick. Overall, the Del Carmen is a ledge-former. It lies conformably on the Telephone Canyon Formation and is conformably overlain by the Sue Peaks Formation. The Del Carmen consists of about 136 m (446 ft) of rudist biomicrite (wackestone-packstone), and has several layers which contain nodular and lenticular chert bodies. The chert is of replacement origin, because beds in the limestone pass uninterrupted through the chert bodies. Macrofossils are partly silicified, and some of the chert bodies may be silicified hash of macerated fossils. Some chert was seen in vertical stringers and with vertical parting. Del Carmen outcrops commonly show recrystallization to various grades of crystalline limestone, and one sample collected about 8 m below the top of the formation contains dolomite.

Petrography--Neomorphism is the dominant diagenetic effect seen in thin section. Fossils have been neomorphosed to sparry calcite, and the micrite matrix has become microspar and pseudospar. Some patches interpreted as finely to medium crystalline pseudospar may actually be shell fragments which have been neomorphosed. Limonite occurs as clusters or seams associated with cavities, pseudospar crystals, or stylolites. All of these features indicate that diagenesis took place in a meteoric realm, though this could be an effect of sampling and outcrop weathering.

Fossils--No fossils were collected from the Del Carmen, for, while they are abundant, they do not weather out well and are hard to remove. Macrofossils seen on outcrop consist of rudists and other pelecypods, while microfossils seen in thin section consist of ostracods and a few types of Foraminifera.

Regional features and depositional environment--Smith (1970) has summarized the distribution of facies within the Fredericksburg Group for central and southwest Texas and northern Coahuila, Mexico. To the east of Big Bend National Park, in northernmost Coahuila, the Del Carmen becomes part of the lower Devils River Formation, and further east changes facies to become rudist limestone of the West Nueces Formation and evaporites and black clayey limestone of the McKnight Formation. In Coahuila to the south, the Del Carmen undergoes facies change into the Aurora Lime Mudstone. In the Big Bend area, the formation thickens westward between the Sierra del Carmen on the east and Santa Elena Canyon and the Yellow Hill Quadrangle on the west. The formation contains rudist bioherms in the Black Gap area of the Sierra del Carmen (St. John, 1965; Smith, 1970).

The lithology and distribution of the Del Carmen indicate deposition on a shallow shelf.

WASHITA GROUP

Sue Peaks Formation

Name and type section--Maxwell *et al*. (1967) named the Sue Peaks from exposures in the Sierra del Carmen. Here and at other outcrops in Big Bend National Park, the formation could be subdivided into a lower shale member and an upper limestone member, partly correlative with the Kiamichi and the Duck Creek Formations, respectively. In the Park, the formation is about 76 m (250 ft) thick. The lower shale member consists of about 23 m (75 ft) of "yellowish-gray and buff marly shale with a few beds of similarly colored thin, marly, nodular limestone." The upper limestone member consists of a 6 m (20 ft) ledge of "massive gray limestone," overlain by 47 m (155 ft) of "thin, gray, nodular limestone beds and some yellowish-gray shale."

Distribution, thickness, and lithology--Exposures of the Sue Peaks in the Yellow Hill Quadrangle are limited to the rim of the Solitario. Here, as at localities in Big Bend National Park, the formation forms a slope between the massive ledges of Del Carmen Limestone below and Santa Elena

Limestone above. The Sue Peaks lies conformably on the Del Carmen, is only about 22 m (72 ft) thick, and is not divisible into lower shale and upper limestone members. It consists of gray, platy-nodular clayey pelecypod biomicrite (wackestone) having 2-5 cm thick interbeds of gray biomicrite that weather drab steel gray. A sample from one of the latter beds contains patches of extremely coarsely crystalline calcite up to 1 cm across, in which are disseminated a few crystals of "limpid" dolomite. Toward the top the formation becomes almost fissile, with beds less than 1 cm thick. The base is generally covered by colluvium and/or alluvium.

Petrography--The platy-nodular biomicrite which composes most of the Sue Peaks interval was examined in thin section. Meteoric diagenetic effects are most prominent--the clayey micrite matrix has been partly neomorphosed to microspar, and pelecypod shell fragments have been dissolved and filled with sparry calcite. Some shells may have neomorphosed to spar, but, if so, no relict structure is preserved. There are a few isolated fine to coarse crystals of possible pseudospar, but these could also be neomorphosed pelecypod shell "prisms." 0.005-0.1 mm masses of very finely crystalline pyrite crystals show alteration to hematite at the edges, and hematite clusters of similar size presumably were originally pyrite. The entire matrix is tinted by a limonite stain.

Fossils--The following fossils were identified from the Sue Peaks Formation:

Adkinsites bravoensis (Böse)
Hemiaster cf. H. whitei
Enallaster cf. E. texana
Neithea cf. N. duplicosta (Römer)
Tylostoma sp.
Protocardia ?

Unidentified fossils include pelecypods, gastropods, a rudist and an ostracod. Fossils are abundant in the Sue Peaks and weather out readily.

Regional features and depositional environment--The lithology and fossils of the Sue Peaks indicate deposition on a shallow shelf which was receiving fine terrigenous clastic material. In Coahuila the Sue Peaks changes facies eastward into the upper Devils River Formation, and to the south becomes part of the Aurora Lime Mudstone (Smith, 1970). According to Smith, the Sue Peaks thins northward to the southern Marathon Uplift, and received clastic input from source areas to the west.

Santa Elena Limestone

Name and type section--Maxwell *et al*. (1967) named the Santa Elena Limestone from exposures at the mouth of Santa Elena Canyon in Big Bend National Park. The massive cliff-former here consists of about 226 m (740 ft) of cherty rudist limestone in 2.4-3.0 m (8-10 ft) beds. The rudists are commonly silicified, and chert is more nodular than in the Del Carmen. The Santa Elena Canyon section is the thickest and least disturbed section measured by Maxwell *et al*. The Santa Elena section in the Sierra del Carmen (Sierra del Caballo Muerto) has a thickness of about 160 m (525 ft).

Distribution, thickness, and lithology--The Santa Elena is exposed over much of the southwestern half of the Yellow Hill Quadrangle, on the flanks of the Solitario dome and Terlingua-Solitario anticline. In the section measured across the rim of the Solitario, the Santa Elena has a thickness of about 236 m (774 ft), and conformably overlies the Sue Peaks. It is the massive, cliff-forming unit that caps the rim, and over most of its outcrop area forms a dissected dip-slope surface on which faults are easily discernible. The Santa Elena is rudist biomicrite (wackestone) containing layers of lenticular and nodular replacement chert. Beds are mostly 1/3-1/2 m thick, but range from 5 cm to 2 m. Bedding planes show the undulosity so characteristic of all the lower Cretaceous limestones. Chert occurs as irregular nodules, which may have oblong, globular or dumbell shapes. Hematite or limonite stain can make the otherwise gray, white, or black chert brownish or reddish. Macrofossils, mostly rudists, are at least partly silicified and commonly show brownish or reddish stains. In some places there are silicification aureoles, which may have centered around a shell hash. One sample collected near the top of the Santa Elena contains finely disseminated dolomite.

The Santa Elena commonly shows solution pockets, and there are small caves in a few places near the juncture of the Solitario and Terlingua-Solitario anticline.

Petrography--The sparse rudist biomicrite also contains abundant Foraminifera, possibly miliolids, along with pelecypods and other fossils, and a trace of silt. Neomorphic effects are many: micrite has become microspar and finely to medium crystalline pseudospar in places, and foraminifer tests are neomorphosed. Pelecypod and rudist shell fragments are partly replaced by chalcedony. The micrite/microspar matrix contains some 0.3-0.75 mm eye-like clots of hematite, which appear as maroon specks in hand specimens. Hematite also occurs as seams beneath microstylolites, and 10-30 μm clusters of aphanocrystalline crystals. Kaolinite, in one sample, occurs in small (less than 1 mm) pockets and cracks, some of which are within foraminifer tests and pelecypod or rudist shells, and in places is associated with pseudospar.

Neomorphic effects indicate meteoric diagenesis, and the presence of kaolinite may indicate acid leaching.

One chert nodule was examined in thin section. It is mostly 5-20 μm chert consisting of clear or white spheres in a brown groundmass. Chalcedony spheres (0.02-0.05 mm) replace fossils, and have mostly brown centers and clear intersections. According to R. L. Folk (personal communication, 1976), the brown areas contain minute liquid-filled bubbles. Some megaquartz lies between chalcedony spheres. There are a few undigested 0.1-0.3 mm patches of micrite in the chert matrix; other calcite has been deposited in cracks, probably during outcrop weathering. The replacement nature of the chert is indicated by (a) beds passing through nodules, and (b) relict fibrous structure in pelecypod shells, which rules out solution-cavity fill.

Fossils--The only fossils identified from the Santa Elena are Toucasia sp. indet. and Neithea sp. indet. Unidentified fossils include other rudists and pelecypods, Foraminifera (miliolids?) and an ostracod. The Santa Elena, like the Del Carmen, yields few collectable fossils.

Regional features and depositional environment--In Big Bend National Park the Santa Elena thickens westward, ranging from about 160 m in the Sierra del Carmen to 226 m at the mouth of Santa Elena Canyon. It thickens further to the north and west to about 236 m in the Yellow Hill Quadrangle. Smith (1970) has shown that the Santa Elena thins southward into northern Coahuila, where it becomes part of the Aurora Lime Mudstone to the south and the upper Devils River Formation at the edge of the Maverick Basin to the southeast. According to Smith, the lower part of the Santa Elena grades southward into the upper part of the underlying, southward thickening Sue Peaks. Smith also interprets the Santa Elena as a shallow shelf deposit that offlaps to the south.

Del Rio Clay

Name and type section--Hill and Vaughan (1898) named the Del Rio from exposures at Del Rio, Texas. Here it consists of greenish clay with thin limestone and sandstone interbeds. This report follows Maxwell et al. (1967) in using the name Del Rio, though the correlative Grayson Marl has priority, becasue the formation is similar to the unit mapped as Del Rio in the Park.

Distribution, thickness, and lithology--The Del Rio is exposed along the flanks of the Solitario and Terlingua-Solitario anticline. In some places on this anticline, outliers of Del Rio are preserved within downdropped fault blocks. The only other Del Rio exposures are along the Yellow Hill Fault. The Del Rio forms a slope separating the Santa Elena Limestone below from the Buda Limestone above, and consists of gray clay-shale containing 1-10 cm thick interbeds of very fine-grained calclithite sandstone and siltstone, and 5-30 cm thick interbeds of nodular, wavy-bedded

Buda-like biomicrite. The limestone is most abundant near the top of the Del Rio, where it increases toward a gradational contact with the overlying Buda. The Del Rio also contains fibrous gypsum veinlets 1 cm wide that are both oblique and parallel to bedding. The Del Rio was measured at two places, on the east flank of the Solitario where the thickness is about 18 m (59 ft), and on the north bank of Salt Grass Draw near Hill 3740 (SC), where the base is covered but the minimum thickness is 47 m (154 ft) (Fig. 6).

Petrography--In thin section, the gray clay-shale shows no visible lamination, but the clay has good preferred orientation. It contains less than 10 percent silt (quartz and feldspar) and has 0.001-0.05 mm clusters of pyrite crystals, some of which are altering to hematite. Hematite also occurs as 0.02-0.15 mm botryoidal clusters of crystals which average 5-10 μm. Limonite is abundant as a matrix stain, as numerous 0.02 mm clusters, and in lenses up to 0.2 x 1.0 mm, and is responsible for the brown weathering color. The clay contains few Foraminifera (globigerinids?), and is devoid of burrows or other disturbance structures.

One of the sandstone interbeds was examined; it is brown, very fine-grained, laminated, tight, calcitic, mature, collophane-bearing glauconitic calclithite. The sparry calcite cement is poikilotopic, and contains suspended 0.025 mm rhombs of "limpid" dolomite. Dolomite also fills tests of the uniserial foraminifer *Cribratina texana*, which is abundant on some bedding planes. Some elongate grains show preferred orientation parallel to laminae, and some are imbricated. Soft grains are compacted and penetrated by other grains. Other fossils include biserial Foraminifera, and echinoderm and mollusc shell fragments. Limestone rock fragments predominate, but some rock fragments may be igneous. Leucoxene is a minor framework constituent. The rock contains some clusters of hematite and pyrite.

The thin limestone interbeds are similar to the overlying Buda Limestone, discussed below.

Fossils--Only two fossils were identified from the Del Rio: *Cribratina* texana (Conrad) from the sandstone interbeds, and Exogyra cartledgei (Bose)* from near the top of the formation. According to Maxwell et al. (1967) Exogyra cartledgei is characteristic of the upper Del Rio.

Regional features and depositional environment--In the Big Bend area, the thickness of the Del Rio varies. This has been attributed to uplift and erosion before (Smith, 1970), during (St. John, 1975; Maxwell et al., 1967) or possibly after (Maxwell et al., 1967) Del Rio deposition. Smith (1970) reports that in northernmost Coahuila the Del Rio lies disconformably on the underlying formation, the top of which is "commonly iron-stained and bored by clams." The Del Rio thins northward and westward to only a few meters across the Devils River rudist limestone trend. In the subsurface in the Maverick basin, it has a thickness of about 120 m (400 ft), and Smith sees this as evidence of pre-Del Rio topography. In the Black Gap area (St. John, 1965), termination of the lower Del Rio and overlap by the upper Del Rio indicate uplift during Del Rio deposition. St. John's isopach map of the Del Rio shows that it thins toward a high which existed where the Rio Grande is today.

The Del Rio also varies in thickness in areas adjacent to the Yellow Hill Quadrangle. It is 40 m (131 ft) thick at Gray Hill in the Agua Fria Quadrangle to the north, and 56 m (185 ft), 30 m (100 ft) and 24 m (80 ft) in the Terlingua district to the south (Yates and Thompson, 1959). Erickson (1953) reported a thickness of about 20 m (65 ft) from the Tascotal Mesa Quadrangle to the northwest. Herrin (1958) reported a thickness of 38 m (125 ft) from the Lefthand Shutup of the Solitario. The Del Rio was not closely studied in the Yellow Hill Quadrangle, but it seems probable that the above features are indicative of uplift and intermittent erosion in different areas before and during Del Rio deposition.

The lithology, thickness, and areal distribution of the Del Rio indicate that it was deposited as a shallow shelf mud. The sandstone interbeds may represent periodic turbidity current deposits.

Buda Limestone

Name and type section--Vaughan (1900) named the Buda from exposures of glauconite-bearing, fossiliferous crystalline limestone at Buda in central Texas.

Distribution, thickness, and lithology--The Buda Limestone is exposed on the flanks of the Solitario and Terlingua-Solitario anticline, along the Yellow Hill fault, and along Terlingua Creek. It consists of dense very light gray, nodular sparse foraminifer biomicrite (wackestone) in beds 0.5 to 0.75 m thick, with individual nodular layers averaging 5-6 m thick. It has medium crystalline calcite veinlets cutting it oblique to bedding. Bedding planes are undulose, giving it the nodular appearance. It weathers to a bleached white or dull gray, and forms a prominent ledge above the underlying Del Rio Clay. On the east flank of the Solitario, the Buda is about 16 m (52 ft) thick.

Petrography--The sparse foraminifer biomicrite shows some dismicritic texture. Disturbed areas are filled with aphanocrystalline to finely crystalline rhombic sparry calcite, perhaps because of patchy neomorphism. Aphanocrystalline to medium crystalline hematite is disseminated throughout the micrite matrix.

Limestone pebble conglomerate or limestone breccia is found within the Buda Limestone at two localities on the east and northeast flanks of the Solitario. The conglomerate/breccia occurs as small pockets within the normal Buda lithology, and is pinkish or pink and white compared to the white, porcelaneous Buda.

At both localities the conglomerate/breccia consists almost entirely of limestone rock fragments, with a few fragments of coarse chert, cemented by very finely to very coarsely crystalline sparry calcite (Fig. 7). On the northeast flank of the Solitario, the rock is a conglomerate with rounded pebbles and granules, and cobbles and boulders up to 0.3 m. Many of these rock fragments are flat, and some are oriented, whereas others are edgewise. The limestone rock fragments here consist mostly

Fig. 7. Hand specimen of limestone breccia within Buda Limestone on east flank of Solitario (left), and three hand specimens of limestone pebble conglomerate within the Buda on the northeast flank of the Solitario (right). These rocks differ strikingly from typical porcelaneous Buda biomicrite.

of Comanchean limestone, but a few are caliche, calcite spar, or dolomite. Other rock fragments are limonitic and hematitic, glauconite-bearing sandstone, and few igneous rock fragments. There is also much reworked Inoceramus prisms and other pelecypod trash. On the east flank of the Solitario, the rock is a limestone breccia, with a great variety of limestone rock fragments ranging from crystalline and dolomitized limestone to normal Comanchean limestone. It also contains a few quartz grains.

The sparry calcite at both localities has rhombic crystal habit and lacks meniscus or pendulous cement/framework relations. For the smallest size mode (4-16 μm), rhombic habit has been interpreted to indicate cementation in a meteoric diagenetic realm (Folk, 1974b), and the cement/framework relations and larger crystals indicate a phreatic environment. The conglomerate on the northeast flank of the Solitario shows equant to bladed, very finely to medium crystalline crusts on framework grains, among coarsely to very coarsely crystalline random equant spar, and shows some grain compaction. The breccia from the east flank of the Solitario has pyrite altered to hematite, and the calcite cement shows several size modes between very finely and coarsely crystalline, suggesting possible neomorphism of the cement during recent vadose weathering.

The field relations, areal extent, geometry, and petrography indicate a solution, cavern-collapse, sinkhole type of origin. Another possibility, suggested by the rounded pebbles at the northern locality, and by the variety of limestone rock fragments at both localities, is that the pockets of conglomerate/breccia are remnants of sediment transported by streams which drained the Solitario during an earlier stage of uplift and/or erosion.

Fossils--The only fossils identified from the Buda are Neithea subalpina (Böse) and Budaiceras hyatti (Shattuck)*. Unidentified fossils include gastropods, pelecypods, globigerinids and other Foraminifera, echinoderm fragments, and an ostracod. Like the Del Carmen and Santa Elena, the Buda yields few collectable, identifiable fossils.

Regional features and depositional environment--In Big Bend National Park and eastward to Del Rio, the presence of a middle marly unit within the Buda makes the formation divisible into three members (Maxwell et al., (1967). This division can also be made in northern Coahuila, but disappears to the south (Smith, 1970). The Buda in the Yellow Hill Quadrangle lacks the three-fold subdivision, but a middle marly member is reported from the Buck Hill (Goldich and Elms, 1949), Tascotal Mesa (Erickson, 1953), and Santiago Peak (Eifler, 1943) Quadrangles to the north.

The Buda shows local thickness variation attributed in part to pre-Gulfian erosion by Maxwell et al. (1967). In the Yellow Hill Quadrangle and surrounding areas, the Buda thickens toward the south, from 16-21 m (52-69 ft) in the Yellow Hill, Tascotal Mesa, and Agua Fria Quadrangles (Erickson, 1953; Moon, 1953) to 21-35 m (70-115 ft) in the Park and the Terlingua district (Maxwell et al., 1967; Yates and Thompson, 1959).

The lithology and fossils of the Buda indicate shallow shelf deposition.

Gulfian Series

TERLINGUA GROUP

Boquillas Formation

Name and type section--Udden (1907) named the Boquillas Formation from exposures at the old Boquillas post office, about 7½ mi (12 km) northwest of the present-day town of Boquillas (Maxwell et al., 1967). Boquillas Formation and Terlingua Group are here used in the sense of Maxwell et al. (1967), who included the lower member of Udden's (1907) Terlingua Beds in their upper member of the Boquillas. These authors divided the Boquillas into two members, the Ernst, lower, and San Vicente, upper, which are separated in the Park by an erosion surface. The Ernst overlies the Buda Limestone and consists of "silty limestone flags, siltstone, and calcareous clay." The San Vicente is a "flaggy chalk-marl unit," with basal beds very similar to the underlying Ernst. The clay content increases up section toward a gradational contact with the overlying Pen Formation. In the Park, the Ernst-San Vicente contact is placed at the top of the *Coilopoceras* Zone, about 30 m (100 ft) above the *Allocrioceras* Zone. The contact between the San Vicente and the Pen Formation is placed 5-6 m (15-20 ft) above the *Inoceramus undulatoplicatus* Zone. In Big Bend National Park, the Boquillas Formation averages about 244-259 m (800-850 ft) thick (Maxwell *et al*., 1967).

Distribution, thickness, and lithology--The Boquillas Foramtion is exposed over much of the northeastern two-thirds of the Yellow Hill Quadrangle. The Ernst and San Vicente Members are not distinguished in this report, because almost all of the Boquillas exposed is Ernst.

The Boquillas consists mostly of gray, laminated, clayey, sparse foraminifer biomicrite (wackestone) in beds a few to several centimeters thick, separated by laminae of calcitic clay. The flaggy biomicrite weathers to a bleached yellow color. The *Allocrioceras* Zone is a dense, brown-weathering bed about 10 cm thick which contains abundant *Allocrioceras hazzardi* and an unidentified straight cephalopod. It supports a dense growth of lechuguilla, which with its dark color make the bed darker than surrounding Boquillas on air photos. Over much of the highly-dissected outcrop area of the Boquillas, outliers of this bed represent the highest part of the Boquillas exposed. The bed is shown on Plate I by the symbol "cccc."

Beds of the upper Boquillas are also gray, laminated, clayey, sparse foraminifer biomicrite but contain more clay and are fissile. The Fizzle Flat Lentil described by Moon (1953) in the Agua Fria Quadrangle, overlies the flaggy biomicrite sequence of the lower San Vicente, is fissile and weathers yellow. Outcrops of this rock are almost devoid of vegetation. Overlying the Fizzle Flat is fissile, gray-weathering clayey foraminifer biomicrite which grades upward into calcitic clay-shale. Several chalky, white-weathering biomicrite beds are within the shale just below the base of the Pen Formation. One of these represents the *Inoceramus undulatoplicatus* Zone, but no *I. undulatoplicatus* were found at the few available outcrops.

The thickness of the Boquillas was not measured because nowhere is a complete section exposed. Moon (1953) measured a complete section in the bed of Terlingua Creek (southern Agua Fria and northeastern Yellow Hill Quadrangles), and the parts of his "Boquillas-Terlingua units" corresponding to the Boquillas as used here have a combined thickness of about 216 m (708 ft). Erickson (1953) estimated the maximum thickness of the Boquillas to be about 183 m (600 ft) in the Tascotal Mesa Quadrangle to the northwest. McKnight (1970) measured a thickness of 305 m in the Bofecillos Mountains to the southwest. Yates and Thompson (1959) reported thicknesses of about 3-5 m (1000 ft) and 332m (1090 ft) for the interval beneath the "Inoceramus undulatoplicatus gray beds" in the Terlingua district to the south. In the Yellow Hill Quadrangle, the Boquillas is probably 250-350 m thick.

Petrography--The clayey, sparse foraminifer biomicrite contains much pelecypod shell debris, chiefly Inoceramus prisms, in addition to abundant Foraminifera. Foraminifer tests are filled with equant to bladed, very finely to coarsely crystalline rhombic sparry calcite cement. Laminae are discontinuous; most are a function of clay content, but some result from packing of foraminifer tests. The micrite matrix is stained by limonite, and contains 5-500 μm aggregates of aphano- to finely crystalline hematite and botryoidal aggregates of spherical clusters of crystals.

The brown-weathering bed containing Allocrioceras hazzardi shows greater neomorphic effects than other Boquillas samples. The matrix is microspar with 0.5 mm long pods of micrite that are parallel to lamination. Areas of very finely to medium crystalline rhombic spar in the matrix are diffuse at edges, and were probably formed by patchy neomorphism. Length-slow chalcedony partly replaces some macrofossils.

The rhombic sparry calcite cement and neomorphic effects indicate that diagenesis was predominantly meteoric.

Fossils--The following fossils were identified from the Boquillas:

Durania?

Pycnodonta congesta (Conrad)

Allocrioceras hazzardi Young

Inoceramus cf. *I. pictus* Sowerby*

Inoceramus spp.

Baculites sp.

Unidentified fossils include Foraminifera (pelagic, uniserial and biserial), ostracods, pelecypods, an ammonite and a straight cephalopod. Globigerinids are the predominant Foraminifera, but uniserial and biserial types are also abundant near the top of the Boquillas. The unidentified ammonite may be *Peroniceras* sp.; it was found with unidentified pelecypods, tracks and burrows just below the Fizzle Flat Lentil in a brown-weathering bed, the appropriate position for the *Peroniceras* beds of Maxwell *et al.* (1967). One of the *Inoceramus* species collected from the upper Ernst Member correlates with the second member of the Austin Chalk of central Texas (Keith Young, personal communication, 1975).

Regional features and depositional environment--As already noted, the Boquillas shows an overall southward thickening in areas adjacent to the Yellow Hill Quadrangle.

The lithology and fossils of the Boquillas indicate deposition on a shallow shelf (which was part of the Coahuila Platform) subject to intermittent influx of terrigenous fines.

Pen Formation

Name and type section--Maxwell *et al.* (1967) named the Pen Formation from exposures at the Chisos Pen, north of the Chisos Mountains in Bed Bend National Park. The Pen "includes Udden's (1907a, pp. 33-41) middle and upper members of his Terlingua Beds and the unit called Terlingua equivalent by Adkins (1933, pp. 270-271, 451-452)." In the Park, the Pen consists of about 67 to 213 m (219 to 700 ft) of yellowish-weathering calcitic clay containing beds of chalk and sandstone, and abundant calcareous concretions.

<u>Distribution</u>, <u>thickness</u>, <u>and</u> <u>lithology</u>--The Pen is exposed mostly in down-dropped fault blocks within the eastern half of the quadrangle. It weathers to form slopes or badlands. The formation lies conformably and with gradational contact on the underlying Boquillas, and consists of gray, calcitic, foraminiferal clay-shale. In a few places, the Pen contains thin chalky limestone beds.

The thickness of the Pen was not measured because even a good partial section is not exposed. It seems probable that only the lower Pen is exposed in the quadrangle; outcrops within fault blocks can be traced into areas where the base of the Pen is exposed. Also, the Tertiary Pruett Formation, which unconformably overlies the Pen, has cut out the Aguja Formation and part of the Pen, although the Aguja may be absent because of recent erosion in places where the Pruett also is missing. The Aguja unconformably overlies the Pen in areas immediately to the north, east, and south. Finally, sandy facies of the Pen, which characterize the upper part of the formation (Maxwell <u>et</u> <u>al</u>., 1967; McKnight, 1970), are absent.

The thickness of the Pen varies greatly in surrounding areas. It is absent in the Tascotal Mesa Quadrangle, where the Pruett unconformably overlies the Boquillas (Erickson, 1953). In the southern Agua Fria Quadrangle, the Pen is about 102 m (335 ft) thick, the thickness measured by Moon (1953) for the middle and upper members of his "Upper Boquillas-Terlingua Unit." In the Bofecillos Mountains, McKnight (1970) reported a thickness of about 61 m or 200 ft, although in places the Pen has been cut out completely, and Tertiary rocks overlie the Boquillas. In the Terlingua district, Yates and Thompson (1959) reported a thickness of about 305 m (1000 ft) for the Terlingua Clay, which includes part of the upper Boquillas as used here. Variations in thickness result from erosion during pre-Aguja and pre-Pruett times, but the Pen still shows an overall southward thickening.

<u>Petrography</u>--The calcitic foraminiferal clay-shale contains fine, discontinuous laminae. Most laminae result from variation in clay content, and in some places laminar patches of clayey micrite alternate with

calcitic clay. A few laminae are formed by packing of foraminifer tests along bedding planes. The clay contains minor amounts of quartz and feldspar silt, detrital opaque minerals and pelecypod shell fragments. A sample collected north of Hill 3412 (EC) contains clay intraclasts 0.1-0.7 mm long, which contribute to lamination.

Foraminifer tests are filled with sparry calcite cement, which can be rhombic or have radiaxial extinction. Some 25 μm dolomite crystals occur in the sample that has the clay clasts, along with isolated crystals of medium crystalline sparry calcite. Aphanocrystalline hematite is arranged in 10-200 μm aggregates, and limonite stains the calcitic clay matrix. An authigenic opaque mineral, probably pyrite, occurs in some foraminifer tests, and shows alteration to hematite at edges.

A chalky limestone bed sampled from the Pen is a sparse foraminifer biomicrosparite (wackestone). It contains globigerinid Foraminifera, Inoceramus prisms, and possible ostracods. The matrix is entirely neomorphosed to microspar, and foraminifer tests are filled with sparry calcite that can be rhombic or have radiaxial extinction. Aggregates 15-200 μm of aphanocrystalline hematite occur in the matrix and completely fill some foraminifer tests. Limonite stains the matrix.

Fossils--The only fossil identified from the Pen is a fragment of Inoceramus sp. from the limestone bed described above. Unidentified fossils are the globigerinid Foraminifera and possible ostracods. Fossils are extremely rare in the few good Pen exposures in the quadrangle.

Regional features and depositional environment--Like the underlying Boquillas, the Pen thickens southward in areas surrounding the Yellow Hill Quadrangle. The lithology and fossils of the Pen indicate deposition on a shallow shelf which was subject to relatively continuous influx of abundant terrigenous fines. The Boquillas-Pen sequence thus records an increasing supply of fine clastic material to the Coahuila Platform.

Tertiary System

Eocene Series

BUCK HILL GROUP

Pruett Formation

Name and type section--Goldich and Elms (1949) named the Pruett from exposures near the Pruett Ranch in the north-central part of the Buck Hill Quadrangle. There the Pruett consists mostly of tuff, but "includes conglomerate, tuffaceous sandstone and breccia, and tuffaceous freshwater limestone," and intercalated trachyte, basalt and andesite flows. In the Buck Hill Quadrangle, the Pruett unconformably overlies the Boquillas and in some places the Pen, and is 274-305 m (900-1000 ft) thick.

Distribution, thickness, and lithology--The Pruett is exposed only in the extreme northern part of the quadrangle, as small outliers on downthrown sides of faults. It lies unconformably on the Pen Formation, and with the Pen forms a slope beneath the Mitchell Mesa Tuff and/or diabase sills. In the Yellow Hill Quadrangle, the Pruett consists of a basal limestone-pebble and cobble conglomerate, overlain by calclithite sandstone with minor amounts of interbedded gray and maroon tuff and bentonite. One maroon bentonite bed in the Pruett north of Hill 3964 (NC) contains white chalky limestone nodules.

The thickness of the Pruett was not measured because the section is incomplete, and outcrops are small and isolated. Many outcrops consist only of basal conglomerate and the sandstone immediately above, but some include sandstone, tuff, and bentonite up to the overlying Mitchell Mesa Tuff. Less than one kilometer north of the quadrangle, 0.75 km east of Mesquite Tank in the Agua Fria Quadrangle, a thin section of Pruett capped by Mitchell Mesa is exposed in a cliff above the Pen Formation. The estimated thickness of the Pruett there is 9 m and includes about 3 m of basal conglomerate. The estimated thickness of the Pruett in the Yellow Hill Quadrangle is 10 to 40 m; this variation in thickness may have been produced by recent erosion.

Petrography--Six Pruett sandstone/conglomerate samples were taken above the basal conglomerate from two localities. These samples range from fine-grained sandstone to sandy granule conglomerate, and consist of light grayish-brown, calcitic, tight, submature to mature calclithite. Only two samples are faintly laminated; the rest lack lamination, but all show some imbrication and preferred orientation of elongate grains. The samples also show some grain compaction, indicated by line contacts and penetrations. The most abundant grain type comprises carbonate rock fragments, which are mostly derived from Cretaceous limestone. Comanchean limestone predominates, but the amount of Boquillas rock fragments, including *Inoceramus* prisms, is significant. Some samples contain few pelsparite and other fragments possibly derived from Paleozoic limestone. The next most abundant grain type is quartz, very little of which is recognizable as volcanic. All samples contain a few fragments of chalcedony and/or megaquartz, as well as chert. All samples contain some feldspar, and some contain sandstone and siltstone rock fragments, magnetite, biotite, glauconite, and silicified volcanic rock fragments. The cement is very finely to coarsely crystalline mosaic sparry calcite, some of which is rhombic, indicating cementation in a meteoric diagenetic realm (Folk, 1974a). Hematite occurs as aggregates 10-300 μm, and stains parts of the cement. One sample contains 10-750 μm aggregates of aphanocrystalline (?) pyrite. Some of the hematite and pyrite may not be authigenic, but instead derived from Cretaceous limestone fragments.

One of the chalky limestone nodules from a bentonite bed in the Pruett outlier north of Black Ridge was examined in thin section. It is a sandy burrowed dismicrite (= sandy burrowed lime mudstone). Most distinct ovoid burrows are 1-1.5 mm across, but they can range from 0.1 mm to about 4 mm across. Other disturbed areas are less distinct, except for cracks, and may be related to desiccation. All of these voids are filled by very finely to coarsely crystalline, rhombic sparry calcite cement. Terrigenous material ranges from silt to fine sand, and is fairly uniformly distributed throughout the micrite matrix. Sand and silt consist of quartz, some of which is volcanic and euhedral, volcanic rock fragments, some of which are silicified, and opaque minerals (leucoxene, hematite, and possibly magnetite). Some possible carbonate rock fragments may be indistinct burrows.

Fossils--The only fossils found in the Pruett in the Yellow Hill Quadrangle are unidentified high-spired gastropods less than 5 mm long, collected from lower Pruett sandstone. In the Agua Fria Quadrangle, the thicker Pruett section has yielded abundant fossil material consisting mostly of terrestrial vertebrates. Sandstone and conglomerate contain land mammals, including primates, rodents, amynodont rhinoceroses, titanotheres, a horse and artiodactyls; and semi-aquatic reptiles, consisting of crocodiles and turtles. The basal Tertiary conglomerate, where granular, contains teeth of primates, rodents, a bat, and other mammals; and gar scales and turtle scutes. Tuffaceous limestone contains *Planorbis* sp., *Goniobasis* sp.; and molds of freshwater ostracods (Moon, 1953), as well as well-preserved remains of turtles. Calcitic tuffs have yielded steinkerns of a low-spired *Helix*-like gastropod (Moon, 1953).

J. A. Wilson is studying the vertebrate fossils of the Pruett Formation in the Agua Fria Quadrangle, and has compiled the following faunal list for the Whistler Squat local fauna, which consists of fossils collected from the basal Pruett conglomerate and lower Pruett sandstone and conglomerate:

Pristichampsus sp.
Peratherium cf. *P. Knighti*
Peratherium cf. *P. marsupium*
? *Diacodon* cf. *D. bridgerensis*
Scenopagus priscus
Scenopagus curtidens
Talpavus cf. *T. nitidus*
Nyctitherium velox
cf. *Pantolestes*
Centetodon sp. cf. *C. pulcher*
Centetodon sp. B.
Chiroptera
Microsyops sp.

Notharctus sp.

Uintasorex sp.

Omomys cf. O. carteri

? Hemiacodon sp.

Stylinodon sp.

Thisbemys plicatus

Microparamys minutus

Lophioparamys sp.

Paramyid indet.

Mysops boskeyi

Prolapsus sibilatoris

Prolapsus junctionensis

Prolapsus sp. indet.

Proviverra sp.

Carnivore indet.

? Orohippus sp.

Sthenodectes australis

? Epitriplophus sp.

Diacodexis sp.

Malaquiferus sp.

Leptoreodon marshi

Wood's (1973) study of the rodents of this fauna suggested a middle Eocene, probably early Bridgerian age for the lower Pruett. Based on the entire fauna, Wilson (1974) indicated an early Uintan age for the lower Pruett.

The upper Pruett Formation has also yielded vertebrate fossils from localities in the Devil's Graveyard in the Agua Fria Quadrangle. This fauna is being studied by J. A. Wilson and includes the following taxa:

Leptotomus cf. L. kayi

Mahgarita stevensi

Haenodon cf. H. crucians

proviverrine (new genus)

Sthenodectes australis

Amynodon sp.

Protoreodon pumilus

? *Poabromylus* sp.

Together these fossils indicate very late Eocene age (J. A. Wilson, personal communication, March, 1977).

A detailed discussion of Pruett vertebrates is being prepared by Stevens *et al*. (in preparation).

Regional features and depositional environment--The Pruett thins drastically between the Yellow Hill Quadrangle and areas to the north. Lava flows which were used to separate Pruett from Duff in the Buck Hill Quadrangle (Goldich and Elms, 1949) pinch out before reaching the Tascotal Mesa and Agua Fria Quadrangles (Stevens *et al*., 1975). These authors will propose a new formation name for the Pruett-Duff sequence south of where the lavas disappear.

Strata mapped as "Pruett-Duff" by Erickson (1953) in the Tascotal Mesa Quadrangle have been shown to be entirely Pruett by Wilson (personal communication, 1976). These strata are continuous with the fossiliferous Pruett strata in the Devil's Graveyard in the Agua Fria Quadrangle. Erickson's cross-sections show no regional thinning of Pruett and Duff toward the Solitario, and one section (p. 1372) which shows thinning on the northeast flank of the Solitario is based on his interpretation of the Tertiary strata as Pruett-Duff.

In the Agua Fria Quadrangle, Moon (1953) estimated the thickness of the Buck Hill Group, which he thought to be mostly Pruett with perhaps some Duff Tuff, to be about 305 m (1000 ft). The Buck Hill there consists mostly of calcitic tuff, but includes conglomerate, sandstone, breccia, clay-tuff, limestone, and a unit referred to as "yellow conglomerate." The basal conglomerate is about 3-15 m (10-50 ft) thick and contains no local igneous material. Sandstone above the basal conglomerate contains abundant volcanic quartz, much of which occurs as euhedral bipyramids. This same sandstone locally contains abundant petrified wood, including logs up to 18-24 m (60-80 ft) and few stumps in growth position. Above the sandstone is maroon and gray bentonite with interbedded sandstone. The Upper Pruett consists mostly of calcitic tuff, but includes tuff-pebble conglomerate and sandstone in channels. Some of the tuff is cross-bedded, indicating sub~~aerial~~aqueous deposition, and possible point bar sequences have been recognized in it (J. B. Stevens, personal communication, 1974). These Pruett deposits are 8-11 km (5-7 mi) north of outcrops in the Yellow Hill Quadrangle. A detailed discussion of the sedimentology, petrography, and paleoecology of the Pruett in the Agua Fria Quadrangle is being prepared by Stevens et al. (in preparation).

In the Bofecillos Mountains area, the Chisos Formation, which is approximately correlative with the Pruett and Duff Formations, has a maximum thickness of about 320 m (1060 ft), not including the basal conglomerate; the Jeff Conglomerate, thought to be correlative with the basal conglomerate of the Pruett, is about 6 m (20 ft) thick or less, and locally contains igneous pebbles (McKnight, 1970).

In Big Bend National Park, the thickest section of Chisos Formation is about 1070 m (3500 ft) in the Chisos Mountains (Maxwell et al., 1967). Here the Chisos Formation contains three to four lava members, as well as conglomerate, sandstone, and tuff.

The Pruett Formation and correlative deposits thin toward the Yellow Hill Quadrangle from all directions, to an estimated 10-40 m, because of nondeposition and erosion. Considerable Tertiary erosion is indicated by the fact that the overlying Mitchell Mesa Tuff lies above the Duff Tuff in areas to the north and northwest, while in one place in the southern Agua Fria Quadrangle the Mitchell Mesa lies only a few meters above the basal conglomerate of the Pruett. Pruett sandstones in the Yellow Hill Quadrangle are calclithites with little interbedded tuff, while in surrounding areas correlative rocks contain abundant volcanic material and interbedded lavas.

The Pruett section in the Yellow Hill Quadrangle is a thin tongue of lower Pruett. It is possible that some Pruett was removed by pre-Mitchell Mesa erosion. The Pruett in the hills southwest of Agua Fria Mountain is lower Pruett (J. B. Stevens, personal communication, 1974). The Agua Fria intrusive did not influence Pruett deposition, because material derived from the intrusive occurs only in Quaternary alluvium

(J. B. Stevens, personal communication, 1974), and Moon's (1953) map shows the northwest edge of the intrusive cutting the Pruett, indicating a post-Pruett age for this feature. The abundant fragments of Comanchean limestone in the basal Pruett conglomerate and overlying sandstone indicate that the high position of the Solitario and Terlingua-Solitario anticline had been established by the time of Pruett deposition, and influenced thickness and lithology as much as distance from volcanic centers. McKnight (1970) and Corry (1972) have concluded that the dome and anticline had formed by the time of the deposition of the Chisos Formation, because the Chisos pinches out against the flanks of these structures.

The lithology, structures, fauna, and regional features indicate that Pruett deposition was predominantly fluvial, and partly lacustrine. McKnight (1970) concluded that, because of the great areal extent and little relief at the base of the basal conglomerate and Jeff, that these deposits were laid down by streams near base level on a vast pediment surface. The abundance of conglomerate containing pebbles and cobbles almost exclusively of well-rounded limestone fragments also supports this idea. Cross-bedded sandstone, tuff, and conglomerate were probably deposited by braided and low-sinuosity meandering streams. Limestone was deposited in lakes which collected a rain of tuff, and limestone nodules formed in shallow ponds and lakes. Wood (1973) suggests that increasing aridity with time during lower Pruett deposition may be indicated by an increase in the rodent genus _Mysops_, from five percent of the rodents sampled from the basal conglomerate to 51 percent of the rodents in the Whistler Squat local fauna.

Oligocene Series

Mitchell Mesa Tuff

Name and type section--Goldich and Elms (1949) named the Mitchell Mesa Rhyolite from the unit capping Mitchell Mesa in the northwestern corner of the Buck Hill Quadrangle. The rhyolite has a pink groundmass in which are phenocrysts of quartz and chatoyant, tabular anorthoclase that weather out in relief. The rock also contains "gray vesiculated areas and... red inclusions of baked and silicified ash." The Mitchell Mesa weathers to form a resistant ledge above the Duff Tuff. At the south edge of Mitchell Mesa, the rhyolite is about 12 m (38 ft) thick.

Distribution, thickness, and lithology--The Mitchell Mesa is exposed only in the extreme northernmost part of the quadrangle, the southern edge of outcrops southwest of Agua Fria Mountain in the Agua Fria Quadrangle. It weathers to form a resistant ledge above softer rocks of the Pruett Formation, and consists of rhyolitic, welded ash-flow tuff that contains pumice rock fragments and abundant phenocrysts of anorthoclase and quartz. Its thickness was not measured, but is probably less than 10 m (33 ft).

Petrography-- The Mitchell Mesa Tuff is rhyolitic, devitrified, vitric-crystal-lithic ash-flow tuff porphyry. The light salmon pink groundmass has a microeutaxitic appearance in plane light, which is perhaps a vague, remnant shard texture. It consists mostly of laths, wedges or rectangles 1-5 μm long, of quartz pseudomorphous after tridymite and cristobalite. Some 20-30 μm crystals are scattered through the finer ones, and crystals as large as 50 μm help make up the groundmass.

Phenocrysts consist mostly of broad laths of anorthoclase, with some euhedral, embayed quartz crystals 0.2-4.0 mm long. There is a trace of hornblende, 0.1-0.5 mm crystals, altered to hematite at edges. An opaque mineral is probably pyrite altered to hematite at edges, and may represent the precursor of hematite aggregates.

Fibrous, devitrified pumice rock fragments are up to several centimeters long, and contain spherical voids 0.03-0.4 mm across. The larger rock fragments have a few voids several millimeters across filled with anorthoclase crystals a few millimeters long. In hand specimen, the rock fragments show preferred orientation and some appear stretched, giving the tuff a barely noticeable eutaxitic texture.

Regional features and age--Burt (1970) has done the most detailed study of the Mitchell Mesa to date. He estimated that the ash-flow sheet originally covered more than 3100 sq mi of Trans-Pecos Texas and Chihuahua, and concluded that the source was in the Chinati Mountains based on petrographic and field evidence. Burt distinguished two cooling units within the Mitchell Mesa and correlative Brite Ignimbrite, the lower of which occurs in the Yellow Hill Quadrangle and surrounding areas. This lower unit has a maximum thickness of 70 m (230 ft) midway between the Cathedral Mountain Quadrangle, where it is 18-41 m (58-134 ft) thick (McAnulty, 1955), and Bandera Mesa, and thins to the north and south. The minimum thickness is less than one meter on South Lajitas Mesa.

The Mitchell Mesa Tuff is about 12 m (38 ft) thick in the type area in the Buck Hill Quadrangle (Goldich and Elms, 1949), but Graham (1942) measured thicknesses of 21m (70 ft) and 46 m (150 ft) in areas west of there. In the Tascotal Mesa Quadrangle, the tuff is 0-21 m (0-70 ft) thick (Erickson, 1953). Moon (1953) gave no measurement for the unit's thickness in the Agua Fria Quadrangle. In the Bofecillos Mountains area, the Mitchell Mesa is mostly 6-11 m (20-35 ft) thick (McKnight, 1970).

The Mitchell Mesa was correlated with the Brite Ignimbrite of the Vieja Group in Rim Rock Country by Ramsey (1961), who extended further to ncrth and west the minimum area known to have been covered by the ash-flow sheet. In the Vieja, the tuff lies above the Oligocene Capote Mountain Tuff. In the Buck Hill and Tascotal Mesa Quadrangles, the tuff rests on the Oligocene Duff Tuff. In the Agua Fria and Yellow Hill Quadrangles, the Mitchell Mesa lies on upper Eocene lower Pruett deposits, and at one locality is within about 10 m of the Cretaceous Pen Formation.

In addition to thinning southward, the unit thins and pinches out on the flanks of the Solitario and of domes of the Contrabando lowland to the south (Maxwell and Dietrich, 1970; McKnight, 1970). The virtual absence of Mitchell Mesa Tuff in the Yellow Hill Quadrangle reflects this pinchout on the flanks of the Solitario more than regional southward thinning.

Several potassium-argon ages have been determined from Mitchell Mesa/Brite samples. Evernden et al. (1964) listed an age of 29.7 m. y. for the Brite. Wilson et al. (1968) cited this age and gave additional ages of 33.9 ± 1.8 m. y. for the Mitchell Mesa and 33.0 ± 1.1 m. y. for the Brite. F. W. McDowell (1976, personal communication) determined an age of 31.4 ± 0.5 m. y. for the Mitchell Mesa, which was the average of ages obtained from five samples, including a sample of Mitchell Mesa from the Agua Fria Quadrangle, which by itself gave a K-Ar age of 32.3 m. y. McDowell's ages are taken to indicate an age of 31-32 m. y. for the ash-flow tuff.

Quaternary System

Quaternary Alluvium

Distribution, thickness, and lithology--The distribution of alluvium is shown on the geologic map (Plate I) and is limited to beds of streams and their tributaries, except for the thin unmapped terrace gravels previously mentioned (p. 7, 11-12, 14). Alluvium consists mostly of Cretaceous limestone pebbles, cobbles and boulders, either predominantly Comanchean or Gulfian depending on the bedrock on which it lies. The finer grained alluvium is mostly sandy gravel, and forms thick deposits in some places which weather to form smooth slopes. Where large boulders predominate, as in canyons cut into the rim of the Solitario, the alluvium resembles chaotic rip-rap. The maximum thickness of alluvium is estimated to be about 15 m, southeast of a rhyolite plug near the Lefthand Shutup.

Petrography--A sample of the unmapped caliche-cemented terrace gravel, collected north of Hill 3412 (EC), was examined in thin section. It is a limestone pebble conglomerate and sandy flat-pebble conglomerate, cemented by vuggy caliche; the conglomeratic equivalent of a pale yellow, extremely porous, submature calclithite. It consists of Boquillas limestone pebbles, granules and sand suspended in a porous, spongy caliche-micrite matrix. There are trace quantities of sandstone and volcanic rock fragments. The caliche-micrite is full of irregular, jagged voids ranging from about 5 μm to several millimeters long. Tabular voids are preferentially concentrated along the upper sides of flat limestone fragments. The fragments show an overall preferred orientation parallel to the surface on which they were deposited, but some fragments are edgewise, which with the seeming lack of grain support give slabbed specimens an "exploded" appearance. The frothy-looking matrix suggests that the caliche-micrite may be the product of meniscus cementation in large pore spaces that were initially bridged by pendulous cement, which explains the concentration of tabular voids along upper surfaces of flat pebbles. Some patches of microspar occur between the more closely packed clasts; these areas were probably cemented earliest and neomorphosed first. Limonite locally stains parts of clasts and matrix.

Depositional environment--Stream alluvium was and is deposited by ephemeral streams. The thin unmapped terrace gravels are outliers of dissected pediment deposits, probably deposited by shallow braided streams and sheetfloods after heavy rains.

INTRUSIVE IGNEOUS ROCKS

DIABASE

The most abundant, areally extensive, and volumetrically important intrusive igneous bodies are diabase sills; only two of the intrusive masses mapped are not diabase. A few diabase intrusives are plugs or dikes. Bodies of hydrothermally altered diabase are discussed separately in the section entitled "Hydrothermal Alteration."

Plugs

Most plugs are small and are exposed on the northeast flank of the Terlingua-Solitario anticline. Their distribution is structurally controlled by the strike of the Boquillas Formation. A plug less than two meters across and too small to map was found about 1½ km southeast of Hill 3743 (NE).

A plug about 0.3 km across with an associated dike intrudes the Boquillas north of Hill 3412 (EC). Another diabase plug the same size intrudes Del Rio, Buda, and Boquillas on the northeast flank of the Solitario. This plug has faults on its south side, bounding a sliver of Buda overlain by Boquillas. A few small, irregular diabase plugs intrude the Pen Formation; one of these is southeast of Hill 3252 (EC); the others are east of Pink's Peak.

Some plugs have yet to be uncovered by erosion. One of these is in an area characterized by gray, resistant hills of baked and contact-metamorphosed Boquillas limestone, about 2½ km north-northeast of Pink's Peak. One of the hills has a small outcrop of diabase at its top, as well as a small dike on both west and east sides. Other diabase bodies in this area consist of dikes, and a partly unroofed sill about ½ km east of the quadrangle. The above features make it likely that all of these hills are covered plugs.

Another covered plug was found about 1 km northwest of Hill 3215 (EC); it is a small hill that projects above its flat surroundings, consisting of gray, contact-metamorphosed Boquillas limestone with abundant analcite spherules.

At least two plugs were definitely derived from tops of sills. The north side of the top of Pink's Peak is occupied by a plug, while an outlier of the upper of two diabase sills is exposed around the base of the peak. The relatively large area covered by the sills compared to the area of the plug indicates that the plug was derived from the sills rather than vice-versa. Well-developed, equant polygon columnar joints occur on the north side of the plug; columnar joints are less well-developed in other parts. The joints range from straight to twisted and curved in cross-section. Some joint faces show plumose patterns indicative of tension, while others are longitudinally grooved. The plug rock shows both finer basaltic and coarser diabasic textures, with the finest occurring where columnar joints are best developed. Hill 3308 (SE) to the south also has a plug with columnar joints at its top and an outlier of the same sill exposed around its base. The plug and sill outcrops are continuous with each other on the south side of the peak, showing that the plug was derived from the top of the sill.

The small size of most diabase plugs makes it likely that they are irregularities on the upper surfaces of sills, like the irregularities on the top surface of the uncovered sill northeast of Black Ridge.

Dikes

Dikes are few, generally less than ½ m wide, short, have northwesterly trends, and intrude Boquillas and Pen Formations. The dike associated with the plug north of Hill 3412 (EC) trends north-northwest in the Boquillas. The dike consists of two segments, one north of the plug and the other to the south. The maximum length of the dike is about 1.1 km, and the width is less than ½ m.

A dike about ½ km long and less than ½ m wide intrudes the Pen Formation on the downthrown side of the fault east of Hill 3308 (SE). The dike has a north-northwesterly trend, and much of it is actually broken into short *en echelon* segments.

Dikes in the Boquillas north-northeast of Pink's Peak were mentioned earlier; these are only a few meters long, less than ½ m wide, and probably represent small apophyses filling cracks in the country rock above plugs that are still unexposed. In this same area is one dike that is about ½ km long and up to a few meters wide. This dike has an overall northwesterly trend, but is sinuous in plan view, perhaps indicating coalescence of originally distinct en echelon dike segments.

A small dike and plug intrude the Fizzle Flat Lentil of the Boquillas Formation just outside the east boundary of the quadrangle, east-northeast of Pink's Peak. The dike is about 1/6 km long and less than ½ m wide, and has an east-northeasterly trend.

No dikes were found which could have been feeders for the sills. A possible feeder was found exposed in the west wall of Terlingua Creek in the Agua Fria Quadrangle, about 1 km to the north. Here the uppermost and thinnest of three sills is joined by a dike from above.

Diabase Sills

Field Relations

Diabase sills are exposed in a north-northwest-trending belt in the eastern part of the quadrangle. Distribution is controlled by the outcrop area of Upper Cretaceous rocks, principally the Boquillas Formation. The area occupied by sills is roughly seven percent of the quadrangle area, and amounts to about 12.5 sq km or 4.5 sq mi.

Sills intrude all formations between the Buda Limestone and the Mitchell Mesa Tuff, inclusive. In general, sills are found in lower Boquillas in the south, and in upper Boquillas and Pen in the north. In the northernmost part of the quadrangle, a sill intrudes Pen, Pruett and Mitchell Mesa (Plate I). Just to the north, in the area southwest of Agua Fria Mountain, sills intrude the Pruett, and probably intrude Mitchell Mesa Tuff, but contacts with the Mitchell Mesa are not well enough exposed to be conclusive.

Different rock types put different constraints on the sills. The Buda Limestone has very sharp, though undulose, bedding, is hard and dense, and is thus favorable for concordant intrusion. Only two sills are found in the Buda: one in Terlingua Creek (Fig. 8), and the other a hydrothermally altered diabase sill associated with a plug on the southeast flank of the Solitario. The hardness of the Buda, along with the hardness and massive character of the underlying section may account for the Buda being the lower limit of concordant intrusion, and the Santa Elena the lowest observed level of diabase intrusion, and for the relative scarcity of intrusive bodies in these rocks.

The flaggy, clayey, well-bedded Boquillas Limestone is the most favorable unit for concordant intrusion. Sills in the Boquillas have sharp contacts that parallel bedding over large areas. Sills have well-developed cooling joints (Fig. 9), and the best developed cross-sections are hexagons stretched in one direction.

The Pen Formation is the next most abundantly intruded unit but sills in the Pen are the least concordant, because of the scarcity of competent beds.

Sills intruding the Pruett can be traced to outcrops southwest of Agua Fria Mountain. Here concordant and discordant masses interconnect to form a continuous network occupying different levels within the Pruett. This network consists of a series of sills at different levels with connecting sheets, and irregular discordant bodies. Some sills appear swollen, and have columnar joints with equant polygon cross-sections; smaller pods have joints that show an anastomosing pattern in plan view, and appear platy.

Sills show local discordances, of which there are several types. The most common type is an oblique discordant sheet that connects sill segments at different levels, in many places giving the entire body a "monoclinal" appearance. Examples of this occur in several places along the west edge of Black Ridge. Another example is the sill east of, and connected to, the sill capping Hill 3743 (NE). A connecting sheet between two sills is exposed in a stream bed south of Hill 3308 (SE). Such discordances occur in many places in the area southwest of Agua Fria Mountain to the north. Probably the best example of this type of discordance is where the Black Ridge sill, most of which lies above the Allocrioceras Zone in the Boquillas, turns downward to a level below this zone at its

Fig. 8. View southwest toward diabase sill intruding Buda Limestone exposed in wall of Terlingua Creek, northeast part of quadrangle.

Fig. 9. Cooling joints in sill in Boquillas Limestone northeast of Black Ridge, viewed from northwest.

northwest end.

Examples of other types of discordances are the undulatory top surface of the sill northeast of Black Ridge; a "zig-zag," stepped portion of the Black Ridge sill exposed in the south wall of the stream bed southeast of Hill 3704 (NC); and the large, inclined sheet that cuts Pen, Pruett, and Mitchell Mesa in the north.

Bradley (1965) believes that discordances in diabase sills reflect the inverse of the paleotopographic surface of the land above the area intruded, and are isostatic. R. O. Kehle (personal communication, 1975) interprets discordances which connect sills as the coalescence of separate sills intruded at different levels. Stress conditions at the edges are such that coalescence represents the path of least resistance. A combination of these ideas seems necessary to explain stepped sills, in which separate concordant segments are abundant and short.

Intrusive contacts are characterized by baking and contact metamorphism of the country rock, and by chilling of sill margins. Chilled zones are generally the most highly weathered parts of sills. Other, less common contact features include xenoliths, apophyses, and "leaves" of bedded country rock pried up during lateral emplacement of sills. Such "leaves" occur in Terlingua Creek where a sill intrudes the Buda, and at the southeast edge of the sill outcrop at Hill 3252 (EC).

Xenoliths are rare, but where present they are conspicuous. They are baked and metamorphosed, but show no signs of assimilation. The most spectacular xenolith is the large, tilted block of Boquillas limestone within the stepped portion of the Black Ridge sill (Frontispiece). The rectangular block was detached along joint planes. In one of the sills exposed in Terlingua Creek, angular, irregular Boquillas limestone fragments resemble sedimentary rip-up clasts. A similar xenolith over 1 m long was found in the stream bed west of Hill 3630 (NC). One of the thick sills in the Pruett in the Agua Fria Quadrangle contains a large xenolith of Pruett tuff with a petrified tree trunk in growth position (Fig. 10).

Some of the Boquillas outliers on the sill northeast of Black Ridge could be large xenoliths sunk into the sill rather than lying on it.

Fig. 10. View west toward xenolith of baked Pruett tuff in diabase sill southwest of Agua Fria Mountain, north of Yellow Hill Quadrangle. A petrified tree trunk is in place at the lower right edge of the xenolith, beneath the man's feet.

Boquillas outliers on the southernmost sill are not xenoliths but variation in dip indicates differential movement within the large sheet between the two sill levels.

Apophyses are of various types, including small, irregular blebs, as in the Pen northeast of Black Ridge, dikelets one to several centimeters thick, and "fingers." Dikelets are found mostly at bottom contacts, as in the wind gap cut through the sill northeast of Black Ridge. Small finger-like apophyses are found in Boquillas limestone beneath the stepped portion of the Black Ridge sill. The fingers of diabase are parallel to bedding, and have cross section diameters of a few millimeters to a few centimeters. These fingers probably are fillings of conduits preferentially dissolved along bedding planes by escaping volatile substances.

Cross sections of large scale fingers can be seen in Terlingua Creek east of Hill 3310 (NE), at the edge of a small sill (Fig. 11). This could indicate that the sills were emplaced by coalescence of peripheral fingers, as described by Pollard et al. (1975) though the orientation of the section with respect to the sill's edge is unknown. At other places where sill edges are seen in cross-section, as in the draw cutting the northwest edge of the Black Ridge sill, there is no evidence for fingered emplacement.

I estimate the thickness of major sills capping mesas to be less than about 12 m or 40 ft. The southernmost sill is noticeably thicker than other sills, and its maximum thickness near Pink's Peak is probably no more than 50 m (164 ft). Thickness estimates for three sills exposed in Terlingua Creek are as follows: 6m or 20 ft for the lowest; 3 m (10 ft) or less for the next higher sill; and less than 2 m or 7 ft for the highest. Moon (1953) reported a sill 50 ft (15 m) thick in his measured section in Terlingua Creek, but this seems an overly thick measurement.

The sills are multi-leveled. Good examples are in Terlingua Creek, where both Buda and Boquillas are intruded; at Hill 3743 (NE), and in the vicinity of Pink's Peak (Fig. 12). East of Pink's Peak the lower of the two sills is exposed in the west wall of a fault scarp.

Petrography

Terminology used for diabase textures is that of Moorhouse (1959): diabasic or doleritic refers to optically continuous pyroxene patches interstitial to a mesh of plagioclase laths; ophitic refers to optically continuous pyroxene patches that poikilitically enclose plagioclase laths. Subdiabasic or subdoleritic, and subophitic textures are like the above two textures, respectively, except that the pyroxene patches consist of aggregates not optically continuous.

The predominant texture seen in sill samples is subdiabasic; some are diabasic and a few are ophitic. Most sills consist of diabase porphyry, and have plagioclase phenocrysts whose mean size increases up section to the north from about 1 cm in the Black Ridge sill to greater than 4 cm long in parts of the sill that cuts the Mitchell Mesa Tuff,

Fig. 11. Cross-sectional view from southwest of large scale, partly coalesced, tabular fingers at the edge of a small sill exposed in the bed of Terlingua Creek. Coalescence of the slightly offset fingers would produce a short discordant segment of the sill.

Fig. 12. View south from Pink's Peak of two sills, left and right, separated by Boquillas Limestone. A stream (center) has exposed a slightly discordant sheet which connects the two sills.

and up to as much as 8 cm long in a sill in the Agua Fria Quadrangle. The grain size of plagioclase laths is 1 mm or less, based on 21 samples. Diabase in the northern sills contains vesicles filled with analcite and calcite.

Mineral percentages were determined by visual estimate in thin section. Essential minerals are plagioclase, titanaugite, and olivine. Plagioclase averages about 68 percent, ranging from about 35 to 88 percent, and comprises both subhedral laths and larger phenocrysts. In about one-fourth of the samples, plagioclase laths show preferred orientation. In one-third of the samples, the more equant crystals and phenocrysts are sharply zoned.

Titanaugite is the only pyroxene, is generally anhedral, and averages about 18 percent of diabase samples. It generally ranges from about four to 25 percent, but one plug just east of the southern edge of the quadrangle contains about 50 percent pyroxene. In thin section, a third of the samples show distinct concentric zoning of pyroxene.

Olivine occurs both as phenocrysts up to 4 mm long, and in the groundmass. It averages about 7 percent, ranging from about four to 14 percent. In about a third of the samples, olivine shows distinct zoning; in many of these samples the zoned crystals have centers with abundant inclusions of magnetite surrounded by clear rims. Olivine is mostly anhedral, though some samples have a few euhedral phenocrysts.

Accessory minerals comprise magnetite, apatite, and possibly pyrite, with magnetite predominating. Magnetite is probably titanomagnetite, and constitutes about 4-6 percent of diabase. Crystals are mostly euhedral and range in size from a few to 50 μm; they occur in aggregates mostly 0.6 to 1.5 mm across, but which range from 0.15 to 4 mm, based on eight samples.

Apatite averages less than one percent and consists of needles 0.1-1.5 mm long x 2-20 μm wide, poikilitically enclosed in plagioclase. It occurs in most of 21 samples.

Late stage minerals consist mostly of analcite and other zeolites. Analcite is mostly interstitial to plagioclase laths, but also occurs as vesicle fillings. Most vesicles are filled completely by analcite; some vesicles are lined by euhedral analcite crystals and filled by other zeolites or calcite. A few samples have some euhedral analcite crystals in the groundmass, indicating that earliest analcite preceded latest plagioclase crystallization. All but two samples contain analcite, in amounts ranging from about one to ten percent, and averaging about three percent.

Other zeolites are fibrous and mostly length-slow, and occur as clusters or vesicle fillings up to about 1 cm in diameter, and fracture fillings. Only a few samples, all from northern sills, contain them, in amounts ranging from one to five percent.

Most samples contain some amount of the following alteration products: chlorophaeite or bowlingite after olivine, serpentine along cracks in olivine, saussurite after plagioclase, and sericite along cracks in some plagioclase phenocrysts. About a fifth of the samples contain deuteric biotite, in amounts ranging from a trace to about three percent.

No evidence of layering or crystal settling was seen in the field, in hand specimens, or in thin sections, and only the southernmost sill is thick enough, greater than about 30 m or 100 ft, to possibly have experienced settling effects (Walker, 1961). A few concentric bands do appear in one small part of this sill on air photos, and detailed sampling in this area from bottom to top might reveal layers that vary in concentrations of cumulate minerals.

Chemical Data

I follow Parker (1977) in usage of the terms hawaiite, mugearite and basalt: hawaiite has An_{50}-An_{30} normative plagioclase and differentiation index 30-45; mugearite has $<An_{30}$ normative plagioclase and differentiation index 45-65; and basalt has $>An_{50}$ normative plagioclase and differentiation index <30. Priority is given to normative plagioclase composition.

Two chemical analyses of diabase were performed by G. Karl Hoops (Table 2). Samples were taken at the northwest end of Black Ridge and the faulted eastern edge of the southernmost sill; analyses show both

TABLE 2. Chemical Analyses and CIPW Norms for Two Samples of Diabase from Yellow Hill Quadrangle

	SAMPLE →		BLACK RIDGE		SOUTHERNMOST SILL	
CHEMICAL ANALYSIS, wt %	SiO_2		46.49		49.54	
	TiO_2		2.50		2.99	
	Al_2O_3		16.73		15.90	
	Fe_2O_3		1.95		2.70	
	FeO		10.44		8.55	
	MnO		0.18		0.20	
	MgO		6.19		3.46	
	CaO		8.31		6.40	
	Na_2O		4.11		4.52	
	K_2O		0.96		2.47	
	H_2O^+		0.87		1.13	
	H_2O^-		0.27		0.35	
	P_2O_5		0.49		0.79	
	CO_2		0.00		0.07	
	TOTAL		99.49		99.07	
CIPW NORM, wt %	or		5.67		14.59	
	ab		26.51		36.09	
	an		24.37		15.80	
	ne		4.48		1.17	
	wo	di	5.70	11.26	4.32	8.57
	en		2.93		2.09	
	fs		2.62		2.16	
	fo	ol	8.75	17.36	4.57	9.78
	fa		8.61		5.21	
	mt		2.83		3.91	
	il		4.75		5.68	
	ap		1.16		1.87	
	cc		----		0.16	
	TOTAL		98.38		97.63	

to be nepheline-normative hawaiite. The Black Ridge sample is close to being a true basalt with 47.90 percent An in the plagioclase, while the other sample is almost a mugearite with 30.45 percent An in the plagioclase.

Weathering

Sills are most weathered at their chilled margins, otherwise showing only a very thin weathering rind along cooling joint faces. More advanced weathering has affected the thicker southernmost sill, as well as some bodies of hydrothermally altered diabase described below. These rocks weather spheroidally, the size of the spheres being determined by the spacing of joints. In places on the southernmost sill, weathering has produced a several-centimeter thick deposit of brown diabasic detritus (p. 12). A small thin sill to the east of here is uniformly weathered to a brown color.

Some diabase plugs and dikes in the Pruett in the Agua Fria Quadrangle weather to shades of green, pink, and purple, perhaps because of limited hydrothermal alteration.

Hydrothermal Alteration

Several small bodies of hydrothermally altered diabase intrude Santa Elena, Del Rio, Buda, and Boquillas on the east flank of the Solitario and northeast flank of the Terlingua-Solitario anticline. Different intensities of alteration are marked by different rock colors. The rocks are described below in order of increasing alteration.

Four plugs and a sill of a brown or brownish-yellow rock intrude Santa Elena, Del Rio, and Buda Formations on the southeast flank of the Solitario. The sill is continuous with the largest of the plugs; it intrudes Del Rio and Buda to the northeast of the plug, and an erosion-isolated remnant of it is exposed in a cliff of Del Rio to the southeast. The brown-yellow rock is highly jointed and platy, and weathers spheroidally to light shades of beige, yellow and pink. Weathered, bleached-looking beige rock has criss-crossing hematite-filled fractures.

In thin section, the rock shows an intersertal fabric of sericitized plagioclase laths with highly altered and limonite-stained interstitial pyroxene. It includes xenoliths up to 3 mm of recrystallized, medium to very coarsely crystalline calcite. Some calcite forms fan-like arrays up to 6 mm long of fibrous crystals; some are monocrystalline and spherical, and may represent vesicle fillings. Medium to coarsely crystalline calcite partly replaces stubby plagioclase phenocrysts in places. Some of these phenocrysts are zoned, some contain apatite crystals, and some have partly altered to vermiform saussurite. The rock contains some anhedral quartz up to 0.1 mm in diameter. The more highly altered beige rock has almost totally sericitized plagioclase laths, and limestone xenoliths up to 12 mm of recrystallized, very coarsely crystalline, bladed to fibrous, baroque-looking calcite. Hematite in fractures replaces some plagioclase phenocrysts and calcite xenoliths.

A small body of yellow rock cut by red dikelets intrudes the Boquillas on the southeast flank of the Solitario. The rock is exposed in a stream bed southeast of Hill 3914 (WC). The body is probably a sill. It is longest in the horizontal dimension and has a concordant roof, though the bottom is not exposed. Some of the rock has a pinkish color. The red dikelets may be areas of greater alteration along vertical fractures, rather than material injected into them. The rock is also cut by horizontal veins of satin spar gypsum.

In thin section the rock shows a relict intersertal fabric of plagioclase laths, some of which along with the larger phenocrysts are altered to kaolinite. Magnetite is altered to hematite in the reddish dikelet rock, and some hematite replaces the altered, kaolinized phenocrysts.

A few plugs of platy reddish rock are exposed in the top of the Santa Elena Limestone near the juncture of the Solitario and Terlingua-Solitario anticline. These bodies do not protrude above the Santa Elena, and were probably stopped by the overlying Del Rio Clay. The easternmost plug has small yellow areas that resemble the yellow rock described above. Among these red plugs is one small body of the brown rock described above, on the ridge including Hill 4591 (WC).

The red rock shows relict intersertal texture in thin section, the groundmass consisting of a mesh of plagioclase laths with interstitial hematite. Plagioclase phenocrysts have altered to kaolinite. Growing within and replacing many of the kaolinite pseudomorphs are crystals of authigenic quartz up to 0.5 mm across, some of which show hexagonal cross-sections, and many of which have "dust" rings indicating accretionary growth.

In a few places near where the red plugs are found, the base of the Del Rio is indurated and hematite-stained to a dark ochre red, with calcite crystals filling several-centimeter long cavities around which are aureoles of calcite cement. These are places where rising hydrothermal fluids were stopped by the Del Rio.

The fact that hydrothermal alteration of diabase is restricted to the east flank of the Solitario suggests that the altering fluids were derived from an underlying intrusive mass, rather than the diabase bodies themselves. Such an intrusive mass could not have been the one responsible for the uplift of the Solitario, because the Solitario predates diabase. The yellow and red rocks may actually be quartz trachyte which was deuterically altered during emplacement (D. S. Barker, personal communcation, 1977), but they are too altered to confirm as either rock type.

Vent Agglomerate

An outcrop of reddish-brown to brown, brown-weathering agglomerate a few meters across was found within the diabase plug north-northwest of Hill 3412 (EC). The rock consists mostly of basaltic volcanic rock fragments cemented by analcite (Fig. 13). A few carbonate rock fragments were derived from the limestone country rock. Some of the larger, pebble-sized rock fragments are well-rounded, while the smaller granule- to sand-sized particles filling the space between them are angular, which suggests that the rock experienced some grinding. The rock is interpreted to be part of a vent agglomerate which collapsed between magma pulses, became imbedded in the underlying pocket of magma, and was cemented by late stage fluids.

Fig. 13. Hand specimens of agglomerate exposed within diabase plug north-northwest of Hill 3412 (EC). The rock is mostly basaltic volcanic rock fragments cemented by analcite. Some larger rock fragments are well-rounded.

Related Bodies

Mafic sills probably cogenetic with the Yellow Hill sills are exposed mostly in Upper Cretaceous strata to the south and southeast, but also in Upper Cretaceous and Tertiary strata to the north (Fig. 14). These sills are discussed below by area, along with some possibly related plugs in adjacent areas.

Agua Fria Quadrangle--The diabase sills in the Pruett to the north are cogenetic with the northern Yellow Hill Quadrangle sills because some of them are continuous with these sills in outcrop. One sill outlier about 5 km north of Agua Fria Mountain, on the downthrown side of the Fizzle Flat fault, was mapped as a questionable flow by Moon (1953). It intrudes the Pen and perhaps the lower Pruett, is identical to other Agua Fria sills in hand specimen, and is the northernmost exposure of these sills.

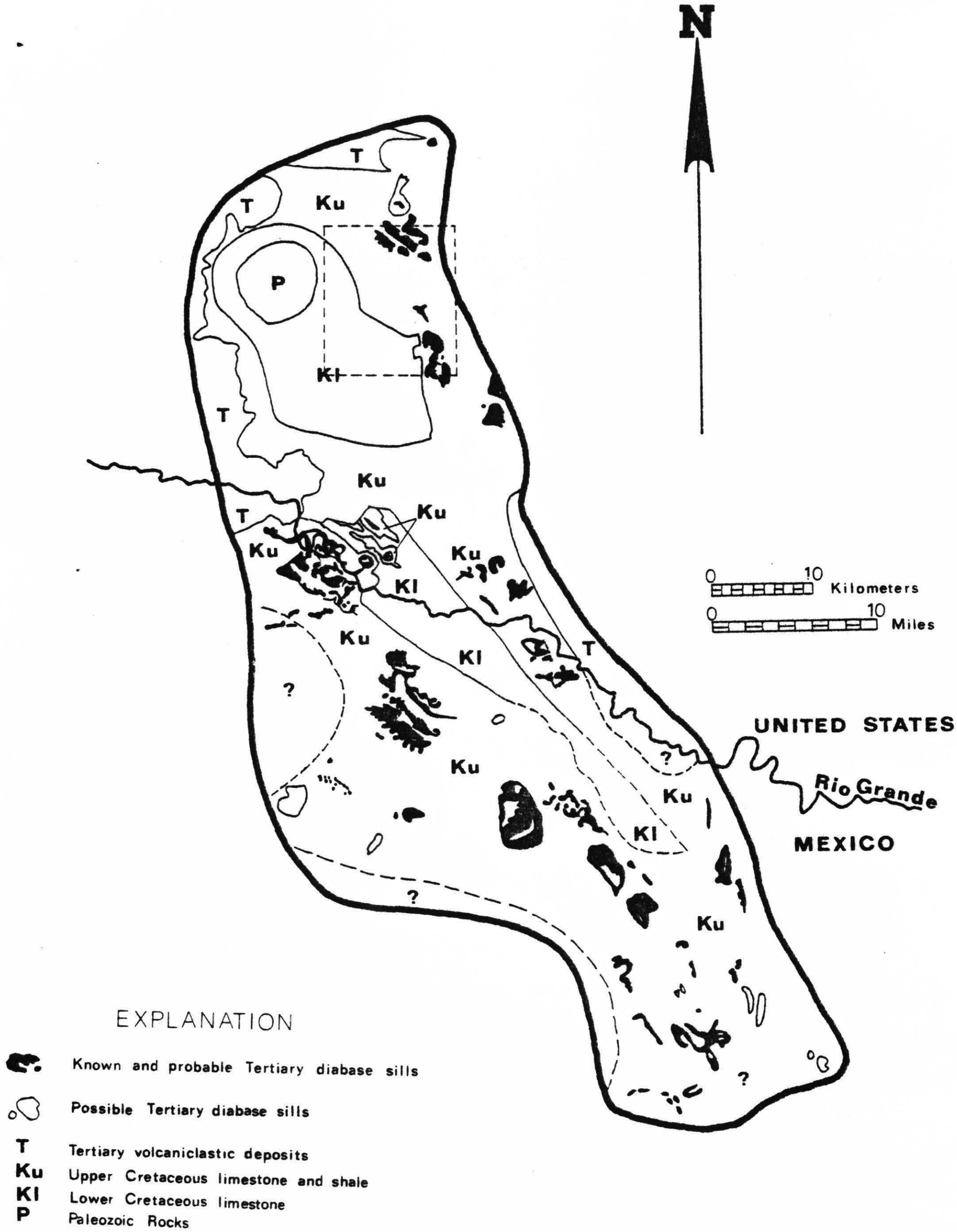


Fig. 14. Sketch map showing larger mafic sills in Yellow Hill Quadrangle and areas to the southeast (other intrusive igneous rocks not shown). Compiled from ERTS imagery, and from mapping in Yellow Hill Quadrangle (dashed), Agua Fria Quadrangle, and Big Bend National Park.

These rocks are being studied by Hatcher (in preparation).

Big Bend National Park--The park has mafic sills exposed on Mesa de Anguila, where they intrude Boquillas, and near Sierra Aguja where they intrude Aguja. Chemical analyses of one sill on Mesa de Anguila and two sills near Sierra Aguja were given by Maxwell et al. (1967), and norms for these were calculated by D. S. Barker. The Mesa de Anguila sill is nepheline-normative hawaiite; of the two Sierra Aguja sills, one is hawaiite and the other is nepheline-normative hawaiite. The rocks are compositionally similar to the northern Yellow Hill sills, in percent An in plagioclase and in K_2O and MgO contents, and intrude the same stratigraphic interval, hence are probably cogenetic with these sills.

Mexico--The Mesa de Anguila sill extends across the Rio Grande to Sierra Ponce, where it has its greatest extent. Other sills are exposed in Upper Cretaceous strata forming a belt that extends to the southeast as much as 70 km from the Yellow Hill Quadrangle, and can be seen on ERTS imagery (Fig. 14). The entire length of this north-northwest-trending belt of mafic sills is about 100 km.

Intrusions in areas to north and northwest--At La Viuda, in the northwest corner of the Tascotal Mesa Quadrangle, a plug of aphanitic, mafic rock intrudes the Tascotal Tuff, which overlies the Mitchell Mesa. A chemical analysis and norms provided by D. S. Barker show the plug rock to be a nepheline-normative mugearite with K_2O and MgO values similar to the southernmost Yellow Hill sill.

A plug of aphanitic, mafic rock intrudes the Mitchell Mesa that caps the cliff on the south side of Puerto Portrillo in the Jordan Gap Quadrangle (D. S. Barker, personal communication, 1976). Barker's chemical analysis and norms show the plug rock to be a nepheline-normative mugearite similar to the La Viuda plug. A plug mapped as analcimitic trachydolerite by Seward (1950) intrudes Tascotal Tuff about 5 km southwest of Puerto Portrillo at Cerro Saludo.

The intrusive mass forming Butcherknife Hill in the Buck Hill

Quadrangle is called "basalt" by Goldich and Elms (1949), but their chemical analysis and norms show that the rock is nepheline-normative and compositionally similar to the above two plugs, hence is probably a mugearite.

Origin

Barker (in press) finds similarities between the Trans-Pecos magmatic province and the Kenya Rift. He suggests that the source of Trans-Pecos igneous rocks was an underlying elongate mantle diapir, as is indicated for the Kenya Rift by gravity data, and that the compositional variety shown by both silica oversaturated and undersaturated rocks can be accounted for by magma generation at different depths with subsequent fractionation and mixing. The nepheline-normative hawaiite and mugearite intrusives of the Big Bend and adjacent Mexico should represent the tapping of a little-differentiated magma at a comparatively great depth in the upper mantle.

The preponderance of sills over the area intruded indicates that the interval intruded was at a shallow depth during magmatic activity. The Boquillas Formation must have been, at the time of intrusion, the first highly favorable horizon for lateral intrusion above the depth where the overburden stress equalled the least principal stress.

Age

The youngest unit cut by the northern Yellow Hill sills is the Mitchell Mesa Tuff, which has been dated at about 31-32 m. y. (p. 51), so a maximum age for these sills is 32 m. y. The youngest unit cut by a probably related body is the Tascotal Tuff, cut by the La Viuda plug. Together these relations suggest a maximum age somewhat less than 32 m. y. for hawaiite and mugearite intrusives in the northernmost part of the belt shown in Fig. 14.

Potassium-argon ages were determined by F. W. McDowell (Table 3) for samples collected from Black Ridge and the southernmost sill (Plate I) and for a sample collected by J. B. Stevens and J. A. Wilson from the sill immediately northeast of Black Ridge, at its northwest end in the Agua

TABLE 3. K-Ar data, diabase sills, Yellow Hill and Agua Fria Quadrangles.

SAMPLE AND DESCRIPTION	MATERIAL	%K	$\%^{40}$*Ar	^{40}*Ar (x 10^{-6} scc/gm)	Age (m.y.) ±2σ
Diabase from outlier at northwest end Black Ridge, Yellow Hill Quadrangle	Whole Rock	0.8395 0.8481	54.7 54.6	1.091 1.126	32.7 ± 1.3
	Plagio-clase	0.2177 0.2232	12.2	0.3101	35.0 ± 2.3
Diabase from east side southernmost sill, Yellow Hill Quadrangle	Whole Rock	2.069 2.100	71.4 68.6	3.331 3.388	40.1 ± 1.5
Diabase from north-west end of sill northeast of Black Ridge (Agua Fria Quadrangle)	Whole Rock	0.8329 0.8234	41.5 42.5	1.091 1.048	32.2 ± 1.5
	Plagio-clase	0.2121 0.2083	15.3 15.4	0.2727 0.2612	31.6 ± 2.3

*Radiogenic component

$\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$; $\lambda e = 0.584 \times 10^{-10}\ yr^{-1}$; $^{40}K/K = 1.19 \times 10^{4}$ Atom/Atom

Fria Quadrangle. The two northern sills gave similar ages, averaging slightly greater than the 32 m. y. maximum age indicated by field relations. The age of these sills is probably slightly less than 32 m. y. The southernmost sill gave a significantly older 40 m. y. age. Though there is no sufficiently precise corroborative field evidence for this 40 million year date, it is plausible that diabase sills were emplaced over a several million year period. Because of the marked favorability of the Boquillas Formation for sill emplacement, the sills were probably rapidly emplaced during a few short pulses of mafic intrusion. If we accept the 40 million year K-Ar age of the southernmost sill, then the minimum span of the period of intrusion of mafic sills shown in Fig. 14 is the eight million years from about 40 million years to 32 million years ago.

RHYOLITE

A rhyolite plug about 0.7 km across is exposed on the northeast flank of the Solitario (Plate I); it is in contact with Santa Elena Limestone and also cuts Del Rio Clay. It may have intruded as high as the Buda. Erosion has removed overlying strata, and carved the plug into an amphitheater-like area. A low area separates knobs on the eastern margin from the high, cuesta-bounded north margin of the plug.

The rock is flow-banded and platy at its contact near the Buda cuesta, and agglomeratic in the knobs, containing pebble-, cobble-, and boulder-sized pieces of Buda and a great variety and abundance of other rock fragments. Most of the rock fragments are pebble-sized, and consist of siltstone and chert. In both hand specimen and in thin section, the rock resembles welded ash-flow tuff.

The rock shows a devitrified, glassy groundmass in thin section, with some glassy veins showing partial devitrification. Rock fragments comprise chert, siltstone, and recrystallized carbonate rock fragments consisting of microspar to very coarsely crystalline pseudospar, some with zoned crystals. Rock fragments are bordered by partly devitrified glass rims 0.03-0.1 mm wide. Zoned siderite rhombs 0.2 mm or less invade borders of many rock fragments, and completely replace some. Some rock fragments are partly replaced by finely to medium crystalline calcite as well, and can have aphanocrystalline calcite filling cracks. The groundmass contains abundant calcite inclusions; those 0.1 mm or less may be carbonate rock fragments, but many of those up to 0.4 mm have rhombic crystal shape and replace the groundmass. Mafic minerals have been completely altered to limonite.

The intrusive field relations, the resemblance to welded ash-flow tuff, and the abundant rock fragments together suggest that this rhyolite body is a vent or volcanic neck.

?ANALCITE SYENITE

A small intrusive body in the southeastern corner of the quadrangle was mapped from air photos. It appears to be associated with the nearby Sawmill Mountain intrusion, which Lonsdale (1940) mapped as analcite syenite.

CONTACT METAMORPHIC ROCKS

Contact Metamorphic Rocks Associated With Diabase Intrusions

Field Observations

Where diabase intrusions, especially sills, have been emplaced in Boquillas Limestone, the main effects on the adjacent country rock are darkening and increased susceptibility to weathering. Gray is the most common color of these rocks. Colors range from gray, weathering to gray, to black, weathering to gray, black or orange. While contact metamorphism generally hardens the limestone country rock, contact metamorphic rock weathers softer in many places. An example is beneath the Black Ridge sill, where diabase talus creeps down the soft rock beneath the sill, but does not cover the limestone further below. Much of this rock resembles the Pen Formation in the field; examples are beneath the sills capping Hills 3743 (NE) and 3252 (EC) (Fig. 23).

Another contact effect is the development of analcite spheres a few to several millimeters in diameter. Such spheres develop a few meters from sill contacts, as beneath the sill northeast of Black Ridge; they were also found in country rock overlying an unexposed plug northwest of Hill 3215 (EC). Flat nodules up to ½ m long, found in Boquillas limestone at one place several meters beneath the southernmost sill, may be contact metamorphic, like those described below for the trap-door dome.

The greatest distance that metamorphic effects extend from a contact as observed in the field, is about 6-10 m; it is likely that less obvious effects extend several meters further. In places where country rock is preserved both above and below sills, contact effects seen in the field appear less pronounced above sills than below them.

Mineralogy

Contact-metamorphosed Boquillas limestone samples were studied in thin section and minerals were identified by X-ray diffraction of slab or powder. Rocks collected at or near contacts contain grossularite, hydrogrossular, apophyllite, or some combination of these minerals. Rocks collected further from contacts contain analcite, and some contain plagioclase. All rocks contain recrystallized calcite.

The most highly altered contact rock was collected at the basal contact of the sill northeast of Black Ridge, in the southeast wall of the wind gap which cuts it. Once a laminated foraminifer biomicrite, the rock is now massive, greenish-gray, and consists of zoned, euhedral hydrogrossular crystals in a matrix of anhedral apophyllite crystals. The hydrogrossular crystals have inclusion-rich centers with clear rims, and average about 0.03 mm; the apophyllite crystals average about 1 mm. A few calcite crystals, 0.02-0.2 mm, remain unreplaced by apophyllite. This rock lacks any original structure of its parent, except for possible vague relict laminae in a few places.

A rock collected at the basal contact of the sill at the northwest end of Black Ridge also contains hydrogrossular, but mostly in laminae spaced a few millimeters apart. The matrix is recrystallized mostly to microspar, with some finely to coarsely crystalline pseudospar. Laminae and foraminifer tests are intact. Preferentially metamorphosed laminae consist of 0.002-0.02 mm hydrogrossular crystals in apophyllite and replacement quartz. Some hydrogrossular is also present in calcite laminae, and apophyllite also fills vertical fractures.

A sample collected near the base of a Boquillas limestone outlier on the southernmost sill, north-northeast of Pink's Peak, consists of micro-pseudospar calcite with finely crystalline grossularite and hydrogrossular crystals. Laminae are preserved, along with globigerinid tests and Inoceramus prisms.

Textural relations in the above samples indicate that grossularite and hydrogrossular occur as replacement of calcite matrix, and formed earlier than apophyllite, which replaced the calcite surrounding the garnets and also filled fractures. Droddy (1974) observed the same relations between these minerals in his detailed study of contact-metamorphosed Boquillas and Pen samples associated with the Bee Mountain soda microsyenite intrusion north of Study Butte, Texas.

In samples taken a few to several meters from diabase contacts, analcite is the chief noncarbonate constituent. Analcite occurs as spherical patches 0.05 to 0.35 mm across, which replace calcite matrix. These patches commonly occur as aggregates, which make up the several millimeter spheres seen in hand specimens. Analcite crystals also occur as a fracture filling with finely to coarsely crystalline calcite, and replace 0.03 to 0.5 mm of calcite on either side of some fractures. Some ragged patches of analcite "float" in calcite fracture fill, and so probably replaced the vein calcite.

In analcite-bearing rocks, most of the calcite has recrystallized to microspar and finely to very coarsely crystalline pseudospar. Laminae and fossils, including foraminifer tests, are preserved; in a single sample, adjacent laminae may be distinguished by their differing analcite contents. Of seven analcite-bearing samples, three were collected below diabase sills, three were collected above sills, and one was collected from between two sills.

Two of the samples collected below sills came from beneath the sill northeast of Black Ridge, in the southeast wall of the wind gap southeast of Hill 3695 (NC); the other came from beneath the sill capping Hill 3215 (EC). All three have analcite spheres and vein fillings, and in all but the last, the original micrite matrix has recrystallized to microspar or finely crystalline pseudospar.

One of the three samples collected from above sills came from a Boquillas outlier on the sill northeast of Black Ridge. The other two were collected from darkened, spherule-rich Boquillas which conceals underlying diabase between this sill and the southeast end of Black Ridge. All of these samples contain metamorphic plagioclase. In the first of these, the matrix has been replaced by analcite, but scattered laminae contain substantial microspar and blades of finely crystalline pseudospar. Inclusions of 2-10 μm recrystallized calcite rhombs are scattered throughout the analcite matrix. Veins containing both analcite and calcite are cut by veins filled only with calcite. Metamorphic plagioclase occurs as 0.02-0.03 mm equant, wedge-shaped or lath-shaped crystals in both analcite-rich and calcite-rich laminae. One of the other samples consists of analcite spheres (0.2 mm) and sphere aggregates in a matrix of analcite and microspar calcite. Plagioclase occurs as equant 0.02 mm crystals in both analcite- and calcite-rich parts of the rock. The other sample consists of very coarsely crystalline pseudospar with analcite spheres (0.05-0.2 mm) and sphere aggregates, in which are 1-10 μm inclusions of recrystallized rhombic calcite. Some laminae are almost entirely replaced by analcite. Plagioclase occurs as 0.02-0.03 mm equant crystals in analcite.

In the sample collected from between two sills, much of the original micrite matrix has been replaced by analcite. Unreplaced lenses of micrite (2 x 10 μm to 0.1 x 0.5 mm) parallel to lamination remain, in which are clusters of equant to bladed, very finely to medium crystalline pseudospar. Limonite occurs principally as a matrix stain, and aphanocrystalline to finely crystalline pyrite occurs in 0.005-0.1 mm lenses.

Contact Metamorphic Rocks Associated With Trap-Door Dome

Field Observations

The general appearance of the trap-door dome rocks is described in the discussion of the dome (p. 100). The main contact metamorphic effects shown by these rocks (Boquillas Limestone) in the field are darkening and increased resistance to weathering. At one place on the northeast flank of the dome, in the lower part of the roof, flat, circular nodules have formed which contain greater concentrations of metamorphic minerals than the enclosing rock. The gray nodules are resistant and weather to a rust or burnt orange color; many of them grew together in clusters that are parallel to the bedding of the enclosing rock.

Mineralogy

Samples were collected at different levels within the roof, the lowest ones being closest to the underlying intrusion. All of the samples contain grossularite, and most contain replacement quartz. Samples have intact foraminifer tests, but vary in preservation of lamination, ranging from laminated to massive to banded, with banding at an angle to the original laminae. All samples except the lowest one were collected along a northwesterly traverse across the southeast flank of the dome.

The lowest sample is a nodule taken from the northeast flank of the dome. It consists principally of densely packed aggregates of grossularite crystals in a matrix of finely to medium crystalline calcite with some replacement quartz. The recrystallized calcite retains discontinuous laminae and intact foraminifer tests. Grossularite crystals are mostly euhedral, average about 10 μm, and occur in aggregates averaging 0.04-0.05 mm. Quartz is anhedral, or fibrous with radiaxial extinction and mostly negative elongation; it occurs in 0.02-0.1 mm aggregates.

The next highest sample is massive, consisting of a network of ramifying aggregates of zoned, euhedral grossularite crystals in recrystallized calcite. In some parts of the section, grossularite aggregates form lenses roughly parallel to former laminae. The very finely to medium crystalline calcite includes some bladed crystals which may be neomorphosed shell fragments. Quartz is indicated in the X-ray diffraction pattern but was not seen in the thin section. Some feldspar crystals were seen, as well as bladed pseudomorphs of analcite, having "pebbled" appearance under crossed nicols imparted by inclusions of the pseudomorphed mineral (apophyllite?).

The next highest sample is laminated, with laminae now distinguished by their grossularite or recrystallized calcite content: laminae of finely to coarsely crystalline calcite alternate with laminae consisting mostly of zoned and euhedral grossularite crystals averaging about 40-50 μm (range 10-100 μm).

Similar compositional layering also characterizes the next sample: laminae consist of grossularite-rich layers alternating with layers comprising grossularite, very finely to finely crystalline calcite, and replacement quartz. Grossularite crystals average 25 μm and range from about 8 μm to 50 μm, and some are zoned. Quartz includes bundles of several μm-long fibers, and 0.1-4 mm-long crystals which contain inclusions of grossularite and calcite.

The highest sample collected is texturally the most severely altered. A vague relict lamination parallel to the original bedding is almost completely obscured by convoluted, alternately light calcite-rich and dark grossularite-rich bands (Fig. 15). The bands intersect the relict laminae at all angles, indicating that the bands are of metamorphic origin, and are not primary features, such as stromatolites, that have been accentuated by contact metamorphism. Intact foraminifer tests and pelecypod fragments parallel to the relict laminae also indicate this. The calcite is very finely to finely crystalline; grossularite is zoned and euhedral, ranging from 0.01 to 0.075 mm across. Crystals of quartz 20-30 μm long occur in rare patches up to 0.5 mm across. Clusters up to 0.4 mm of hematite and rare pyrite altering to hematite are aligned with the calcite- and grossularite-rich bands. This sample is representative of only a small area (several meters) within the level sampled, located near the center of the dome, though the dome may have other such areas. This part of the dome should have experienced greatest extension, and it may be that intersecting joints related to doming provided the means by which escaping fluids could preferentially alter the country rock. One possible explanation for the origin of the banding in the rock is the moving, perhaps pulsing, of diffusion fronts through the rock, in liesegang fashion.

Fig. 15. Hand specimens, all correctly oriented, of contact-metamorphosed Boquillas limestone from uppermost part of roof of trap-door dome. Rock consists of convoluted, alternating grossularite- and calcite-rich bands which have obliterated bedding. The two end samples show the rock as it appears on outcrop; the center samples have been slabbed and etched, and one is stained with a mixture of Alizarin Red S and potassium ferricyanide. The grossularite-rich bands preferentially weather, etch, and stain, perhaps because their interstitial calcite grains have greater surface area than calcite in the lighter bands.

CHERT BRECCIA KNOBS

Peculiar red and white chert breccias are exposed on the east flank of the Solitario, on a dip slope of Buda Limestone at or near its contact with the overlying Boquillas Limestone (Plate I). They occur as lumpy, dark red knobs, which project sharply above the flat dip-slope surface of Buda and resemble small intrusive plugs (Fig. 16). They are small, ranging from one or two to perhaps 10 m across and from about one to five meters high. The five knobs found constitute less than 0.001 per cent of the map area.

The breccias consist of white clasts in a rich, maroon-colored matrix (Fig. 17). The clasts are generally rectangular, ranging from a few millimeters to more than one meter long, and are randomly distributed in the matrix with no discernible sorting.

Field Relations

Of the five breccia knobs, one is at the updip edge of the Buda cuesta, while the other four occur together at the downdip edge of the cuesta, near the present Buda-Boquillas contact. These last four show conclusive relations with the Boquillas (Fig. 18). The Boquillas near the contact is brecciated and reddened in places. The clasts in the knobs here range from completely silicified fragments to partly silicified fragments which resemble pieces of the nearby Boquillas. The most conclusive feature is a chert breccia dike, a few meters long and less than 1/3 m wide, associated with one of the knobs (Fig. 18). This dike crosses the contact to intrude the Boquillas, and like the knobs contains a spectrum of clasts which include some that are indistinguishable from the surrounding Boquillas Limestone. The dike establishes the intrusive nature of the knobs, and supports the identity of the clasts indicated by the knobs. Though the outcrop area of these few knobs is restricted, others may be concealed by the greater thickness of Boquillas east of its outcrop edge.

Fig. 16. View north toward knob of red and white chert breccia exposed on dip slope of Buda Limestone, east flank of Solitario. Orange pack, right center, gives scale.

Fig. 17. Hand specimens collected from chert breccia knob. On right is typical breccia with deep maroon matrix and laminated, white rectangular clasts. At left is laminated, lighter maroon chert with darker chert in a few laminae and fractures; it is probably part of a clast which was only partly transformed into "matrix."

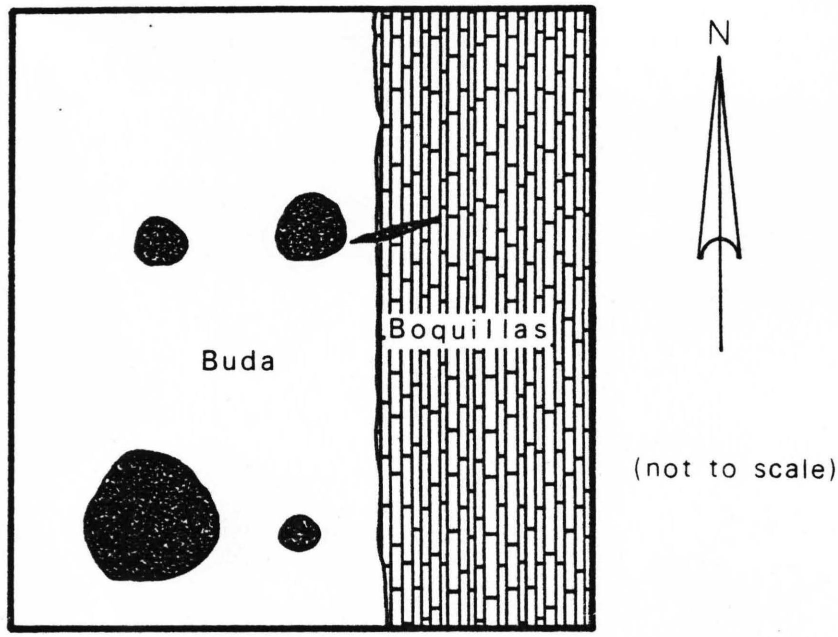


Fig. 18. Sketch map of all but one of the breccia knobs found (the largest knob shown here is about five meters in diameter). Dike near upper right knob crosses Buda-Boquillas contact.

Petrography

The clasts consist of laminated, ½ to 3 μm, white (N 9) chert containing abundant 1 μm bubbles and sparsely disseminated 1 to 2 μm hematite crystals. There are also aggregates of hematite crystals that are pod- and lens-shaped and up to 1 mm long. Parts of the clasts were invaded by the very dark red matrix parallel to the relict lamination, and, where this was stopped in an incipient stage, an orange stain outlines the preferred laminae. The clasts contain many hollow, 20 to 200 μm-diameter spheres which consist of subradially arranged, 5 to 70 μm megaquartz crystals. The fact that many of these spheres are linked together in pairs and triplets indicates that they are silicified pelagic Foraminifera rather than radiolarians or silicified calcispheres. Many of the spheres' walls are encrusted with hematite aggregates, and most of the spheres have been sheared into wavy lenses, which with the hematite pods give the rock a eutaxitic appearance in thin section.

The matrix of the breccias is a very hematitic chert which typically lacks a distinct megascopic structure. Hand specimens and thin sections show that this red "matrix" actually consists of the fragmented, hematite-stained remains of larger fragments like the white rectangular ones. It is made of randomly-oriented, smaller pieces of laminated chert containing sparsely disseminated crystals of megaquartz and coarser chert, and a network of ramifying aggregates of 1 to 2 μm hematite crystals, held together by structureless, almost opaque, hematitic chert. The overall color is very dark red 5 R 2/6, but varies from dusky red 5 R 3/4 in the lighter laminae to blackish red 5 R 2/2 in the darker laminae, fractures, and interstices. The abundance of hematite in the richly-stained "matrix" made it difficult to estimate the size of the chert, but it is comparable to the size of the chert in the white clasts. Abundant large (few millimeter to greater than 1 cm), irregularly-shaped void spaces are spaces between the smaller, less coherent fragments that compose the "matrix."

Some areas of the red matrix are laminated like the white clasts with the laminae offset by fractures that have been filled with structureless, more hematitic, opaque chert (Fig. 17). Such areas contain the same hollow, hematite-encrusted megaquartz spheres as the white chert, and 1 μm bubbles, both of which the typical red chert characteristically lacks; and abundant pods and lenses of hematite, concentrations of which make up the laminae. There are also sparsely disseminated megaquartz crystals and terrigenous silt. These areas probably represent large, formerly light-colored clasts which have been completely reddened by hematite growth along laminae from the edges, and are in an incipient stage of brecciation in the transformation of clasts into "matrix."

Megaquartz veins cut both the clasts and the "matrix," and within them cut hematitic lenses, layers, and veins. Megaquartz also lines the spheres in both chert types and the large void spaces in the "matrix." Short hematitic segments in some megaquartz veins indicate that the latest hematite deposition could have been contemporaneous with at least initial megaquartz precipitation; but megaquartz was predominantly after hematite.

Stable Oxygen Isotopes and Temperature of Formation

Stable oxygen isotope analyses were performed by L. S. Land on fragments of white chert clasts, for which a $\delta^{18}O$ (SMOW) value of $+21.9\ ^{0}/00$ was obtained. Using Knauth's (1973) equation for quartz-water fractionation, isotopic temperatures were determined for different water types which possibly could have silicified the breccia (Table 4).

WATER TYPE	ASSUMED $\delta^{18}O$ ($^{o}/oo$)	TEMPERATURE OF ISOTOPIC EQUILIBRIUM (°C)
Local Meteoric*	-8.1	34°
SMOW (=normal marine)	0.0	79°
Magmatic	+10.0	179°

($\delta^{18}O$ chert = $+21.9^{o}/oo$)

Table 4. Possible temperatures of silica-laden fluid which silicified breccia.

*Inferred from a contour map of δD in precipitation in the U.S. (Taylor, 1974)

The heaviest possible water (magmatic: $\delta^{18}O \sim +10^{o}/oo$) would have silicified the breccia at a temperature of about 179°C. However, nowhere is there supporting field evidence for an underlying shallow intrusive. Moreover, in hydrothermal ore deposits, stable-isotope studies show that the fluids responsible for alteration and mineralization of intrusives consist mostly of meteoric water (Taylor, 1974).

It is unlikely that sea water silicified the breccia at a temperature of 79°C, as this would require the brecciation and silicification to have occurred during or shortly after Buda/Boquillas deposition. The sharpness of the fragments that compose the rock, and the straightness of edges and of internal laminae, attest to the coherency of the material at the time of brecciation, and indicate that brecciation was of the nature of brittle fracture rather than "ripping-up" of a still-plastic, thixotropic material.

If meteoric water were involved, silicification at a "sedimentary" temperature of 34°C is implied. The $\delta^{18}O$ of the water used for paleotemperature determination was calculated from the δD value for precipitation in southwest Brewster County, taken from a map compiled by Taylor (1974). The $\delta^{18}O$ of the water is assumed to have been about the same when the breccias formed as it is now, which assumes that the shape of the continent, and thus the pattern of Rayleigh distillation, has not changed much since then. This interpretation is strengthened by a similar map showing paleo-values of Tertiary age for North American meteoric waters (Taylor, 1974). This water type is considered most likely to have carried the silica for reasons mentioned above: its seemingly great contribution to most subsurface fluids, and the probability that the small realm of silicification was in consolidated rock beneath emergent land. Most likely, the breccias were silicified by silica-saturated, iron-rich hydrothermal fluids derived from mobilized meteoric groundwater that circulated into contact with a buried intrusive. If the elevated temperature were attributed entirely to a normal geothermal gradient of about 20°C/km, then the breccias could not have formed much deeper than ½ km below the ground.

Origin

The two most likely hypotheses for the origin of the breccia knobs are: (1) silicification of sinkhole breccias or breccia pipes of collapse origin, and (2) brecciation and silicification of limestone country rock by hydrothermal fluids.

The sinkhole breccia or collapse-breccia pipe origin is suggested by the occurrence of hundreds of collapse-breccia pipes in the Terlingua district to the south (Yates and Thompson, 1959). Such collapse breccias would have been silicified after, not during brecciation, and would thus be "pre-hydrothermal" breccias in the terminology of Bryner (1961). However, Yates and Thompson do not report silicification of any of the Terlingua district breccia pipes. Also, most of the Terlingua breccia clasts show evidence of great downward displacement, and many of the breccia pipes contain clasts derived from more than one formation. Field evidence shows that the breccia knobs considered here formed only within a minute stratigraphic interval at the very base of the Boquillas Limestone, and that collapse, if any, could not have displaced the clasts more than a few meters. It is possible that the knobs extend to some depth below the top of the Buda, but this cannot be checked except by excavation or drilling. Finally, the dike is difficult to explain with a solution-collapse origin. A limestone breccia in the Buda within 50 m of the southernmost breccia knob, of possible solution-collapse origin, has not been silicified.

A "co-hydrothermal" origin (Bryner, 1961), in which simultaneous brecciation and silicification resulted from the direct action of upward-moving hydrothermal fluids, best explains the field, petrographic and isotopic evidence. The breccia dike, the seeming transition of fragments of Boquillas Limestone to chert, and the nature of the "matrix" are all explained by a hydrothermal origin. The calculated isotopic temperatures are plausible. Spherical or chambered fossils in the chert resemble silicified foraminifer tests, and the range of sizes of these megaquartz spheres (20 to 200 μm, based on two samples) is within the size range of the chambers of foraminifer tests in the Boquillas (mostly 10 to 300 μm, with some as large as 600 μm, for 17 samples). The spheres and the lamination of individual chert fragments make the rock greatly resemble a silicified Boquillas foraminifer biomicrite in thin section. The white clasts represent larger fragments of the Boquillas country rock which retained their coherence before silicification, while the red "matrix" represents a mixture of finer particles that has been more intensely brecciated and hematite-stained.

Hydrothermal breccia pipes have been studied by Bryner (1961) and predominantly magmatic pipes were studied by Perry (1961). Perry cites evidence for a pulsing of magma and fluids in the formation of breccia pipes. The breccias here considered are ambiguous. The spectrum of clasts ranging from little-altered Boquillas limestone to white chert clasts to red pulverized matrix argues for pulses, but the small size of the knobs also makes it possible that all were formed in a single pulse during which some clasts were affected more than others.

Hydrothermal mobilization of iron and silica, and alkali and alkaline earth metals, was reported by Keller and Hanson (1968), who described the hydrothermal argillation of a rhyolite flow-breccia. The silica was precipitated as cristobalite, opal and chalcedony, rather than chert and megaquartz, and the iron and silica were mostly derived from the rhyolite itself. In the breccias here considered, the iron and silica must have come from outside the Boquillas Limestone--possibly from a magma at depth or from siliceous Paleozoic rocks, or even the nearby Del Rio Clay, which lies within 20 m of the breccia.

Paragenesis

The following paragenetic sequence is based on a hydrothermal origin of the breccia knobs (Fig. 19):

(1) First there was upward movement of hydrothermal, silica-saturated and iron-rich fluid through vertical fractures at a shallow depth. When the fluid reached the Boquillas, it was probably at first stopped by the relatively impervious clayey limestone, though there may have been some initial fracturing. Some volume of Buda limestone beneath the Boquillas was preferentially dissolved and removed by the pulsing action of the fluid (this accounts for the greater space occupied by the breccia compared to the space occupied by the original volume of Boquillas that contributed to the breccia); minimal solution accompanied formation of the dike.

(2) Brecciation probably began as a collapse process, with the fractured Boquillas dropping into the solution cavity formed in the top of the Buda. The pulsing fluid further brecciated the limestone, producing large rectangular fragments, approximately greater than 5 mm, and smaller fragments set in a finely ground matrix. Then there was initial infiltration of the smaller, less coherent fragments and fine material by the fluid, with hematite deposition and silicification.

(3) Next there was limited brecciation and infiltration of larger coherent fragments, with the same processes continuing to work on the matrix. Foraminifer tests were sheared into lenses and replaced

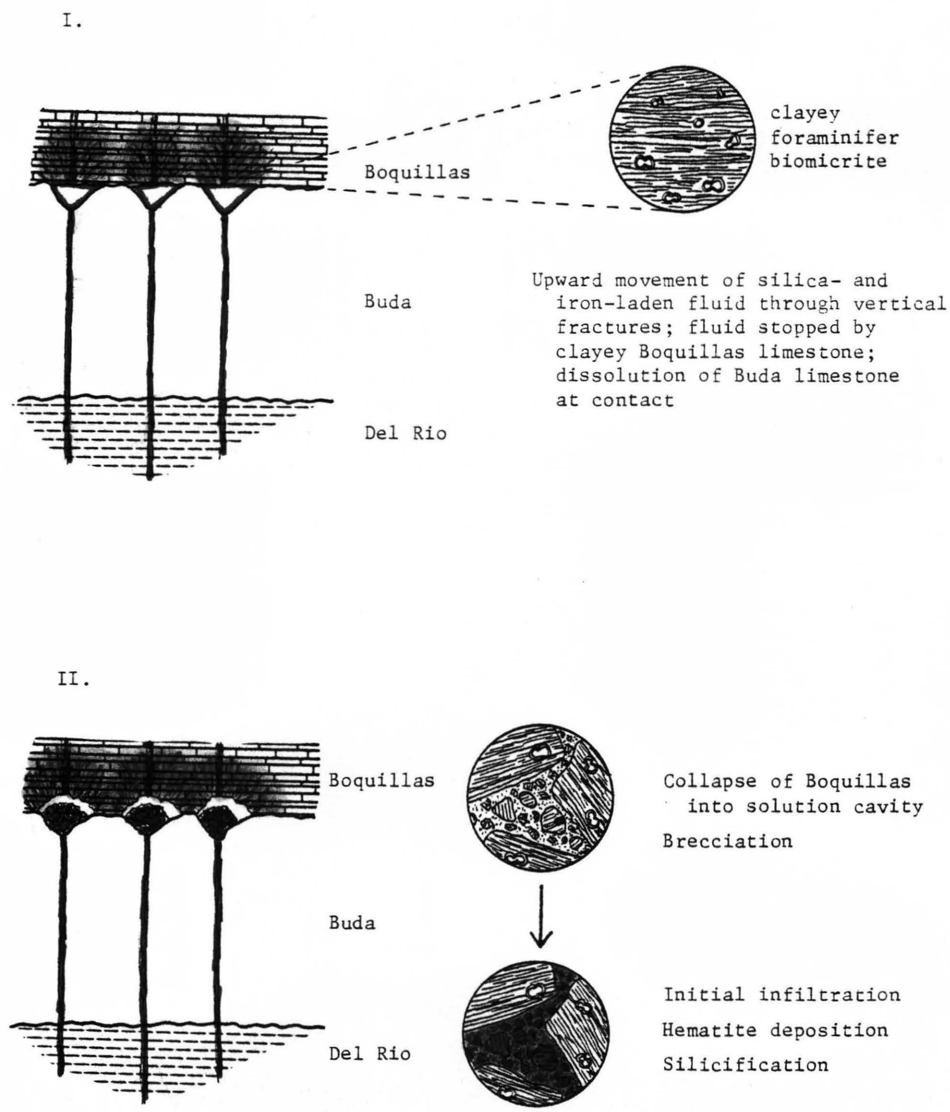
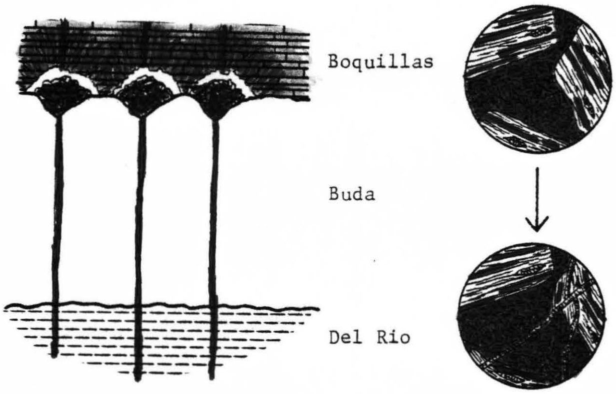


Fig. 19. Paragenetic sequence for chert breccias.

III.



Further collapse,
brecciation,
infiltration,
hematite deposition,
silicification

shear,
replacement of
foraminifer tests by
megaquartz

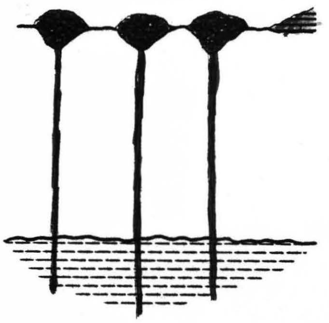
Repeat in pulses?

Replacement of
remaining coherent
clasts by silica;

fracturing;

megaquartz precipitation
in veins, cavities

IV.



Today

Fig. 19. (continued.)

by megaquartz. As the larger fragments were broken into smaller pieces, they were more thoroughly infiltrated and became part of the matrix. This may have been repeated in pulses, with continued collapse.

(4) Finally, the remaining large, coherent fragments were replaced by white, ½ to 3 μm silica. As activity slowed, the rock fractured, and fractures, foraminifer tests, and cavities were lined by precipitating megaquartz.

STRUCTURAL GEOLOGY

The Yellow Hill Quadrangle is located in what Udden (1907) called the Big Bend sunken block, an area between the Terlingua Fault on the southwest and the Sierra del Carmen on the northeast (Fig. 20). Most faults in the sunken block are northwest-trending normal faults. Previous workers in surrounding areas have ascribed structural features to the Laramide orogeny, characterized by broad uplift and northwest-trending folds, and to a later Tertiary period of Basin-Range faulting which produced the northwest-trending normal faults (Moon, 1953; Goldich and Elms, 1949; McKnight, 1970; Maxwell et al., 1967; Stevens, 1969; Wilson, 1972). Laramide disturbance is recorded by the widespread basal Tertiary conglomerates of the Pruett and Chisos Formations; Basin-Range faulting is recorded by early Miocene volcaniclastic siltstone, sandstone, and conglomerate of the Delaho Formation in southwestern Big Bend National Park (Stevens, 1969; Wilson, 1972).

Tweto (1975) defines "Laramide" as applying to orogenic events that occurred between Late Campanian Cretaceous and late Eocene time in the Southern Rocky Mountains region. In the Big Bend region, the Laramide orogeny ranged from the time of the deposition of the Aguja Formation through the deposition of the Pruett and Chisos Formations; gentle warping occurred in Late Cretaceous time, while the folding was Early and Middle Eocene (Wilson, 1972). The Castolon local fauna of the Delaho Formation in the Park dates Basin-Range faulting as post-Early Miocene (Stevens, 1969; Wilson, 1972).

Folds

The style of folding is idiomorphic (Badgley, 1965), which refers to the fact that folds are broad, isolated from one another, and show a variety of plunge directions. Folds are gentle, open, and parallel (concentric). They are also asymmetrical, except for the Solitario dome, which probably has an intrusive igneous origin. Larger folds plunge northwest or southeast; smaller ones plunge north or northeast as well.

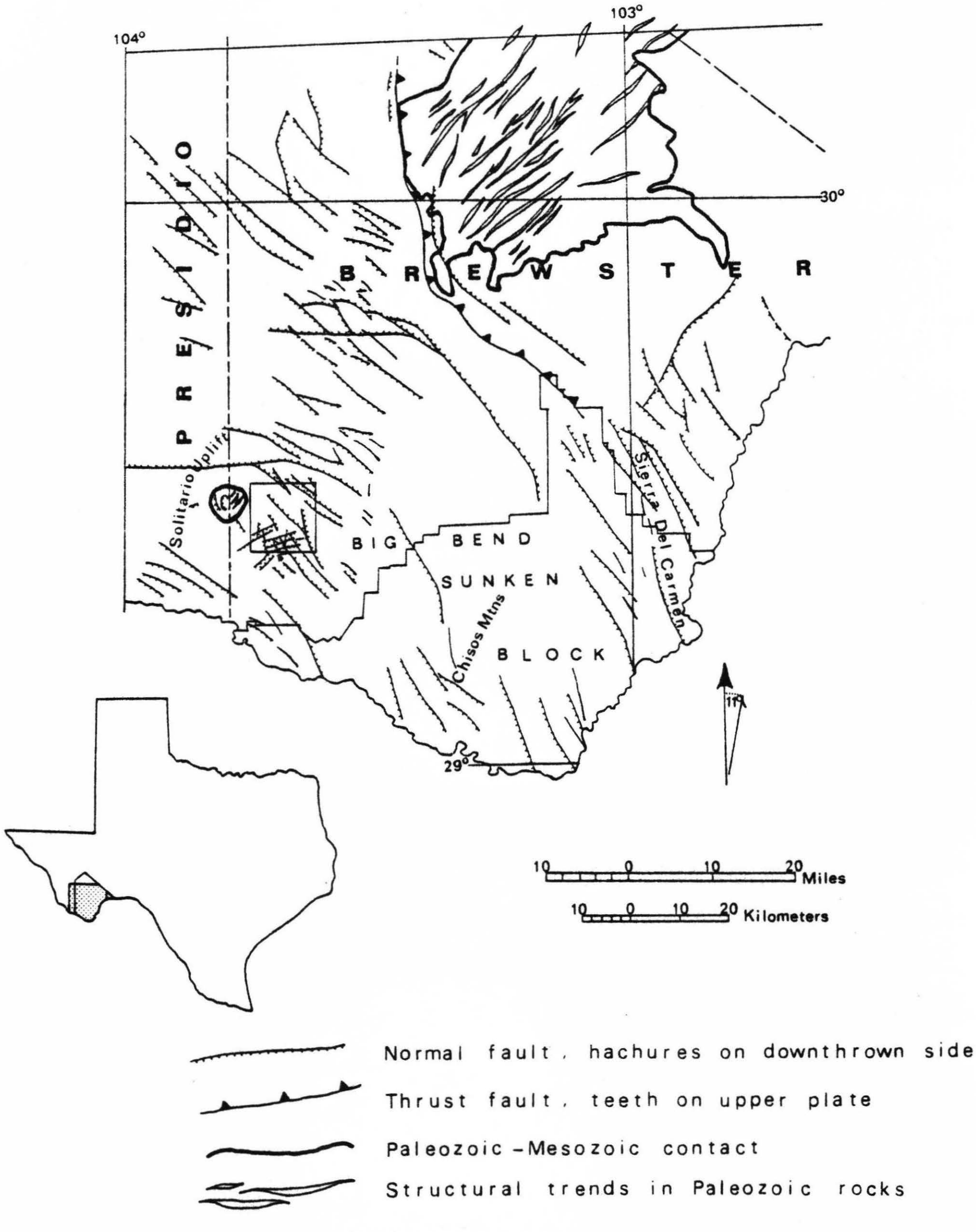


Fig. 20. Structure map of a part of West Texas (after Sellards and Hendricks, 1946; with modifications after Moon, 1953; Corry, 1972; Maxwell et al., 1967; Renfro et al., 1976; Yates and Thompson, 1959; and Plate I).

The Solitario is a symmetrical dome about 13 km in diameter, whose eastern flank occupies much of the western part of the quadrangle. As previously noted (p. 6), earlier authors have assigned it an intrusive igneous, probably laccolithic, origin. Recently C. E. Corry (1975, personal communication) has suggested from geophysical data that the Solitario was formed by emplacement of sills nested one above another. The Chisos Formation thins onto the western flank of the Solitario (Yates and Thompson, 1959; McKnight, 1970; Corry, 1972), indicating that uplift of the Solitario was no later than the time of Chisos deposition. From the Tascotal Mesa and Agua Fria Quadrangles to the Yellow Hill Quadrangle the Pruett Formation also shows thinning onto the northeast flank of the dome, indicating Late Eocene or earlier uplift. Erickson (1953) suggested that the age of the uplift of the Solitario was Late Cretaceous, based on "field evidence." Moon (1953) thought the dome to be "Laramide." The thinning of the Pruett onto the northeast flank, and its corresponding change in lithology from volcaniclastic deposits to calclithite sandstone, suggests that the dome was uplifted just before lower Pruett deposition, in Middle or Late Eocene time. The southeast flank of the Solitario abuts against the northwestern nose of the doubly-plunging Terlingua-Solitario anticline, which led Corry (1972) to conclude that the Solitario predated this anticline, because the previous existence of the anticline would have distorted the circular symmetry of the dome. If the anticline is Laramide, as I consider likely, then the Solitario was uplifted before the period of folding dated by Wilson (1972) as Early and Middle Eocene. A Middle Eocene age seems on balance to be the best estimate of the time of uplift of the dome.

F. W. McDowell (personal communication, 1976) determined a feldspar potassium-argon age of 36.6 ± 1.6 m. y. for a sample of the rim sill of the Solitario, a rhyolite intrusive. This much younger date suggests that emplacement of the rim sill was not associated with the intrusion that produced the Solitario, as thought by Lonsdale (1940) and Herrin (1958).

Tertiary deposits show fault contacts with the Cretaceous except on the west and northwest flanks of the Solitario (McKnight, 1970;

Corry, 1972). On the north and northeast flanks of the Solitario, in the Tascotal Mesa, Agua Fria, and Yellow Hill Quadrangles, Tertiary deposits are in fault contact with the Cretaceous along the Tascotal Mesa and Solitario faults (Erickson, 1953; Moon, 1953; Plate I).

The northeastern flank of the northwest- and southeast-plunging 20 x 13 km Terlingua-Solitario anticline occupies the southwestern part of the quadrangle. The trend of this fold is parallel to the trend of Laramide folds in Cretaceous rocks in the Chihuahua tectonic belt to the southwest, and in the Sierra del Carmen to the southeast. Some previous workers (Maxwell et al., 1967; McKnight, 1970) have thus assigned it a Laramide tectonic origin. Yates and Thompson (1959), however, interpreted the fold as an intrusive igneous structure; they noted that the strike of the eastern part of the southwest flank is easterly, not parallel to Laramide structures. Where the strike changes from a north-northwesterly direction was interpreted as the point where the underlying intrusive mass begins to thin. Corry (1972) believed the anticline to be the surface expression of an ellipsoidal, anticlinal laccolith. Gravity and magnetic surveys could help to resolve this problem, but the regional tectonic origin is here considered most likely because of the trend of the axis of the fold.

Southwest of the center of the quadrangle are a northwest-trending anticline and syncline, involving formations exposed at the surface from the Santa Elena through the Boquillas. The 3 km-long anticline is on the downthrown side of a fault which forms its southwestern boundary, and its northeastern limb is continuous with the southwestern limb of the 5 km-long syncline. Further south, the southwestern limb of the syncline is continuous with the northeastern flank of the Terlingua-Solitario anticline. The northeastern flank of the syncline is bounded by the Yellow Hill fault. These folds are on the northeast flank of the Terlingua-Solitario anticline and parallel its trend, and may be genetically related (subsidiary) to this larger structure. The fault-bounded limbs of the folds form reverse drag against the bounding faults, so it is also possible that the folds formed contemporaneously with faulting.

Two plunging synclines occupy downdropped blocks within the fault system on the northeast flank of the Terlingua-Solitario anticline. Hill 3850 (SW) is a northeast-plunging syncline about 1 km long, involving the Santa Elena through the Boquillas Formations, whose northeast end is truncated by a bounding fault of the block in which it lies (Fig. 21). Hill 3735 (SC) is a north-plunging syncline about 0.6 km long, in the Santa Elena through Buda Formations. These synclines' size, relative isolation, and occurrence within downdropped blocks indicate that they formed by drape folding associated with normal faulting.

Hill 3092 (EC) is a southeast-plunging anticline in the Boquillas and perhaps also the Pen Formation. It is about 2 km long, and is probably at least as wide. The trend of the fold indicates it likely had a Laramide tectonic origin, but its proximity to an intrusive dome, described below, make an origin associated with this feature possible.

Divergent dips around a 4 km circumference along the Boquillas-Pen contact circumscribing Hill 3106 (SE) define the western or northwestern flank of a dome or anticline. It is near the western edge of a large area to the east where intrusive structures (for example, the dome east of Sawmill Mountain to the southeast) are common, and probably has an intrusive origin.

At a few localities on the northeast flank of the Solitario and the northeast flank of the Terlingua-Solitario anticline are small (less than 0.5 km) folds and/or slump blocks which were not mapped. They are best developed southeast of a diabase plug in the northwest corner of the quadrangle, and west of a diabase plug west of Hill 3408 (C). The occurrence of these minor folds on the flanks of the Solitario and Terlingua-Solitario anticline suggests that they formed by gravity adjustment of well-bedded Boquillas limestone to the uplift of these major structures.

Trap-door dome--Hill 3412 (EC) is an elliptical dome trending northeast and projecting conspicuously above its nearly flat surroundings. The dome is in Boquillas Limestone, and is well delineated by its gray color, compared to typical yellow-weathering surrounding Boquillas. This gray color, which is the result of contact metamorphism, helps define a tadpole-like tail extending northeast from the dome proper, which also

Fig. 21. View west from air, showing northeast-plunging syncline of Del Rio, Buda, and Boquillas, in downdropped block of Santa Elena Limestone, on northeast flank of Terlingua-Solitario anticline.

protrudes from its surroundings (Fig. 22).

The dome is bounded by a U-shaped fault around its southwest nose, along which it moved up relative to the Pen and upper Boquillas that are exposed across the fault to the north, west, and south. Displacement is greatest at the southwest tip of the dome, and both of the northeast extensions of the fault die out to the northeast. The fault bounding the southeast limb is covered by caliche-cemented gravel and talus, and could not be traced except by topography. The fault bounding the northwest limb has been "etched" by a small stream, and can be traced to where it dies out into a fold on the flank of the dome. Northeast of here along the tail, the only distinction between the structure and its surroundings is contact metamorphism. Beds of typical yellow-weathering Boquillas can be traced right into the gray, contact-metamorphosed Boquillas, which projects because of differential weathering.

(a)

(b)

Fig. 22. View north from air of Hill 3412 (EC), an elliptical dome (a) in Boquillas Limestone with "tail" (b) extending to northeast. Dome and tail are distinguished from surrounding Boquillas Limestone by gray color resulting from contact metamorphism, and relief.

The topographic expression and corresponding color and contact metamorphism, the anomalous shape and lack of relation to surrounding regional structure, and the U-shaped bounding fault having greatest displacement at the nose of the "U" all support the interpretation that Hill 3412 is a small, elliptical trap-door dome, with relatively small displacement compared to some well-developed examples in the Agua Fria Quadrangle to the north and northeast (Moon, 1953). In this region, this style of intrusion is limited to acidic magmas, and it is probable that the dome is underlain by a rhyolite mass like the Agua Fria domes whose underlying plutons are exposed.

Faults

Most of the faults trend northwest and are downthrown to the northeast. All are nearly vertical normal faults; two small thrusts seen in the Boquillas in the Agua Fria Quadrangle to the northeast probably formed by gravity adjustment to intrusive doming. Fault traces are commonly marked by resequent fault line scarps where hard and soft rock formations have been juxtaposed (Fig. 23), and where faults intersect dip slopes of Santa Elena Limestone. In many places northwest-trending faults have formed grabens and horsts. Drag is common where Boquillas Limestone is cut by faults. Reverse drag occurs along the Yellow Hill fault and associated faults to the southeast; where faults cut sills; and along the fault southeast of Hill 3857 (WC). The fault immediately southwest of Hills 3752 and 3695 (NC) has a thin fault breccia along parts of its trace, which consists of rounded to angular clasts, probably of Pruett sandstone and Boquillas limestone, in a Pen-like clayey matrix.

Though the predominant trend of fault traces is northwest, many northeast-trending faults also occur on the northeast flank of the Terlingua-Solitario anticline (Fig. 24). Here the fault pattern can be resolved into two sets of grabens and horsts that intersect approximately at right angles (Fig. 25). Some of the northeasterly faults offset or truncate northwesterly faults, but this probably is because of differential movement within fault blocks rather than two episodes of faulting. Other examples of faults trending other than northwesterly are those

Fig. 23. View southwest toward resequent fault line scarp along east side of Hill 3252 (EC), a sill-capped mesa. The northwest-trending, near vertical normal fault juxtaposes diabase-capped Boquillas (on the upthrown southwest side) and Pen (on the downthrown northeast side). Flatirons of Pen formed by differential erosion of the soft clay along the fault. Contact-metamorphosed Boquillas limestone just beneath the diabase resembles Pen clay-shale.

Fig. 24. View north-northwest across northeast flank of Terlingua-Solitario anticline toward east flank of Solitario dome. Intersecting faults on the flank of the anticline trend northwest and northeast.

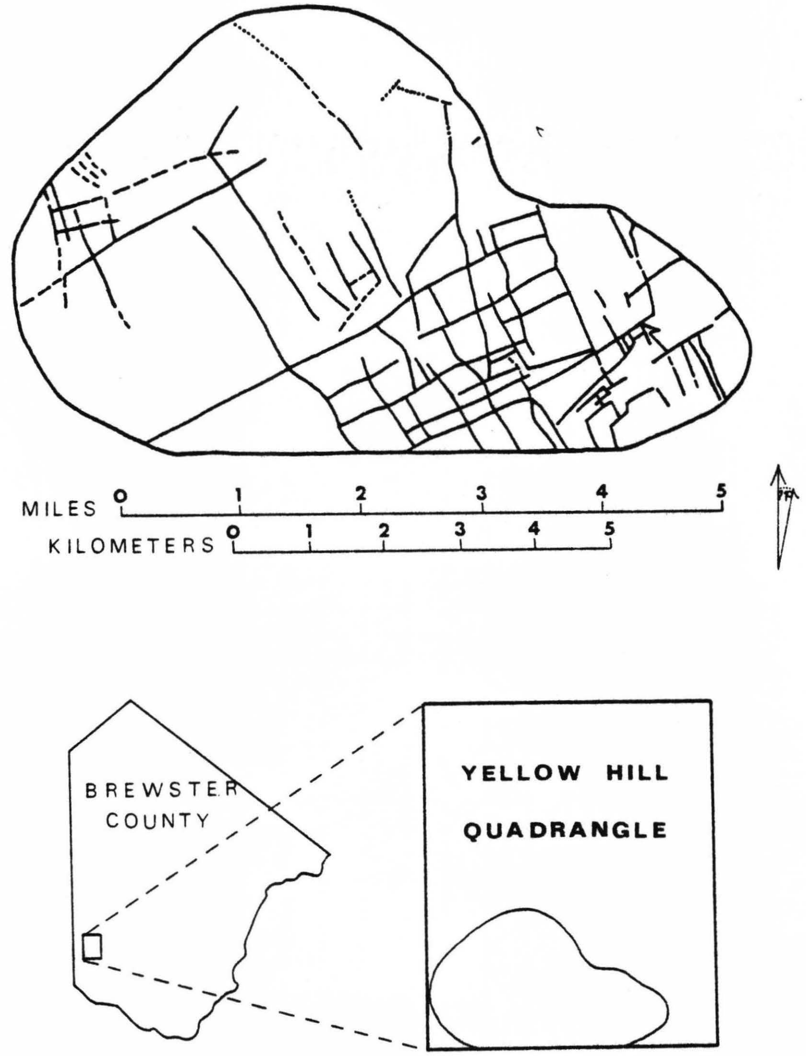


Fig. 25. Faults on the northeast flank of the Terlingua-Solitario anticline. The system can be resolved into two sets of grabens and horsts, which intersect approximately at right angles.

which formed in association with intrusive doming, such as the fault associated with the trap-door dome discussed above, and faults bounding a sliver of Buda and Boquillas associated with a small diabase plug in the northwest corner of the quadrangle. These few faults associated with intrusive structures are the only faults which definitely show a genetic relation to any folds; other faults are independent of folds, and were the product of extension over the broad area within the sunken block.

The trace of the Solitario fault lies northeast of Black Ridge, and trends northwest. The trace continues through the southwest corner of the Agua Fria Quadrangle, trending more westerly, and into the Tascotal Mesa Quadrangle where it joins the Tascotal Mesa fault. In the Agua Fria Quadrangle, the fault has drag in the Boquillas and reverse drag in Tertiary tuff and basalt, mapped by Moon (1953) as Buck Hill but thought by Hatcher (personal communication, 1974) to be Tascotal and Rawls, respectively. The throw on the fault is on the order of several hundred meters.

The Yellow Hill fault trends northwesterly, and to the southeast is continuous with a fault zone immediately east of Pink's Peak. The combined length of the traces of the Yellow Hill fault and associated faults is over 10 km. The Boquillas shows drag against the fault in places. Throw is on the order of a few hundred meters.

The concentration of the northwest- and northeast-trending faults in Fig. 25 on the northeast flank of the Terlingua-Solitario anticline seems anomalous, and the faults are probably not genetically related to the fold. The faults generally have throws of less than 100 m, as estimated by Corry (1972), though a majority have throws ranging from about 50 to 80 m, determined from dip-slope elevation differences on the base map.

Faults in the eastern part of the quadrangle involve Buda, Boquillas and Pen Formations, and diabase sills. In the northeast corner of the quadrangle, in and near Terlingua Creek, are several small faults having both northeasterly and northwesterly trends. These faults cut diabase sills and Boquillas Limestone, and in places juxtapose Buda and Boquillas. To the southwest is a northwest-trending graben with Pen downthrown against Boquillas. To the south is a north-northwest-trending fault zone with Pen on the east downthrown against Boquillas. This zone joins the fault zone that is continuous with the Yellow Hill fault, at a point about 2 km north-northwest of Pink's Peak. Northeast of Pink's Peak is a small (about 1 km long), narrow, horst of Boquillas surrounded mostly by Pen.

Time of faulting--Faults in the Yellow Hill and Agua Fria Quadrangles cut both the Mitchell Mesa Tuff and slightly younger diabase sills, indicating a maximum age of 31-32 m. y. for the faulting. The basalt flow cut by the Solitario fault in the Agua Fria Quadrangle gave a potassium-argon whole rock age of 21.1 ± 0.8 m. y., and a feldspar age of 21.1 ± 5.9 m. y. (F. W. McDowell, personal communication, 1976). The time of faulting was thus about 21 m. y. ago or less. The age and orientation of faults is similar to that of faults in the Castolon area, dated by the Castolon local fauna as post-Early Miocene (Wilson, 1972). Faults that formed during an early stage of Basin-Range faulting in the Rim Rock country have similar age and orientation; dikes associated with faults were dated by Dasch *et al.* (1969), and indicate that the time of faulting for northwesterly faults was about 22 m. y. ago.

Joints

Regularly spaced, extensive systematic joints affect rocks over much of the quadrangle, and vary in spacing in different areas. Wider spacing characterizes thick-bedded and massive rocks, such as the Santa Elena Limestone. The joints are rectilinear in plan view, are almost vertical, and are perpendicular or nearly so to bedding. The main sets are parallel and perpendicular to regional strike, and so constitute strike and dip joints, respectively. Joint faces are smooth; no slickensides or lineations were seen on them, but neither were plumose patterns observed. A few joints are open and filled, most with calcite, but some with gypsum or sandstone and siltstone.

The principal formations affected, both in area and joint density, are the Boquillas and the Santa Elena. The Boquillas is jointed almost everywhere it is exposed, and in a few places jointing has made a sawtooth edge on cuestas. Where the Boquillas is faulted, joints in the vicinity are roughly parallel to faults. The Santa Elena is most highly jointed on the northeast flank of the Terlingua-Solitario anticline, where etching has made joints strikingly visible on air photos. The joints are parallel to the faults in this area, and probably are genetically related to them. The southernmost diabase sill, in an area south of Pink's Peak, has joints not definitely ascribable to cooling; whereas some are non-systematic and curving, others appear systematic and are thought to be tectonic.

Fig. 26 shows two main joint sets that strike N 15° W and N 58° E; minor sets strike N 60° W and N 26° E. Most joints plotted are in Boquillas Limestone, including calcite and gypsum veins and a sandstone dike; a few are in the sill south of Pink's Peak.

The fact that the joints are nearly vertical, associated with normal faults, and include some that were open before being filled, indicates that they are probably extension joints. The orientation and characteristics of joints and faults indicate that the stress field at the time of faulting was extensional with the maximum principal stress oriented vertically and the least principal stress oriented northeasterly, as in the Castolon area (Stevens, 1969) and the Rim Rock country (Dasch *et al.*, 1969).

Clastic Dike

A clastic dike within a small downdropped fault wedge of upper Boquillas Limestone (Fizzle Flat?), at the northwest end of a fault southeast of Hill 3743 (NE), trends N 20° W. The dike ranges from tan, very fine-grained sandstone to gray, coarse siltstone, and averages about 13 cm wide. It appears to terminate at each of the bounding faults of the wedge in which it lies, and because of its small size was not mapped.

The dike consists of calcitic, tight, mature litharenite, in which the calcite cement is poikilotopic. Most of the rock fragments are cherty with abundant dark inclusions, some of which are oxidized to impart red-brown and yellow iron oxide stains; they are probably silicified volcanic rock fragments, which would make the rock a volcanic

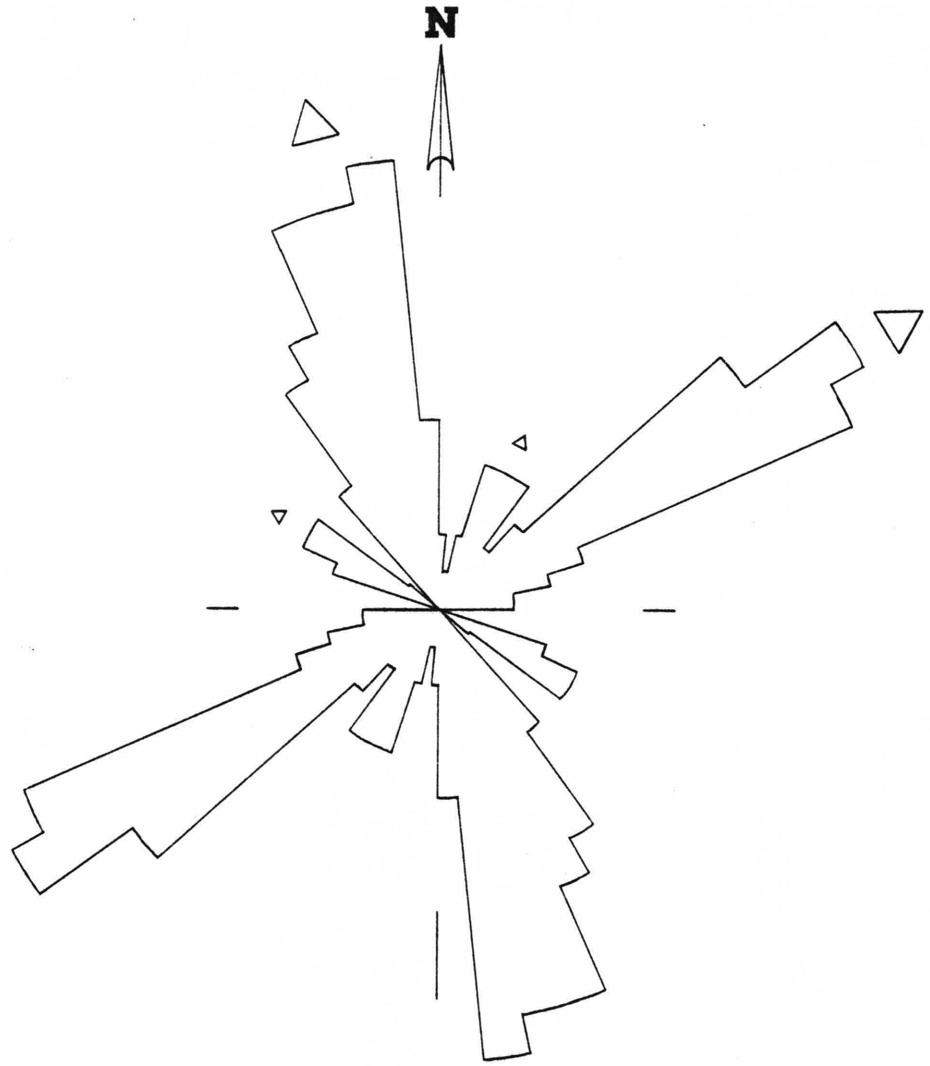


Fig. 26. Strike-frequency diagram of 46 joints, mostly in Boquillas Limestone. Main sets strike N 15° W and N 58° E; minor sets strike N 60° W and N 26° E. Prepared with 3° variants and a ~~30°~~ 9° sliding average.

arenite. The rock contains a trace of glauconite.

Because of the absence of sandstone in the section below the Boquillas, the sandstone had to have been emplaced from above, and was most likely derived from sandstone in either the Aguja or Pruett Formations. Because the Aguja has been completely eroded away in the quadrangle, its character in this area is not known. Pruett sandstones here consist almost entirely of limestone rock fragments, but some contain small amounts of the same "dirty," cherty rock fragments as those in the dike. If the dike was associated with faulting, as is probable, its age would make the Pruett a likely source. A Tertiary age and source of the dike are also suggested by the occurrence of locally abundant clastic dikes in the Pruett in the Agua Fria Quadrangle (Moon, 1953), and in the Duff Tuff in the Jordan Gap and Buck Hill Quadrangles (Seward, 1950; Goldich and Elms, 1949).

The Aguja was stratigraphically much closer to the part of the section intruded by the dike. The Aguja in Big Bend National Park characteristically contains large amounts of variously weathered and silicified volcanic rock fragments, and many samples resemble the dike fairly closely in thin section. However, if the dike is Aguja, then the Aguja was remarkable for having remained unlithified for several tens of millions of years (the time interval between Aguja deposition and Basin-Range faulting).

It is more likely that the dike was derived from a volcanic arenite facies of the Pruett that extended into the area from the north. Sandstone of the Duff Tuff is also a possible source, but it is thought an unlikely one because of its probable thinness, if deposited in the area at all, suggested by the thin section of Pruett beneath the Mitchell Mesa seen just north of the quadrangle.

Veins

Fractures containing calcite fillings were found only on the east flank of the Solitario, mostly in the radial canyons of the rim. In the canyon just south and east of Hill 4473 (NW), the Santa Elena Limestone contains a variety of fillings, in fractures some of which are greater than 2 m wide. Some are filled with a breccia, in which both the clasts and the fine-grained calcite matrix are liesegang-banded. In one such breccia vein the reddish-stained clasts are recognizable as fragments of Boquillas Limestone, which have been displaced downward at least 70 m, but probably greater than 100 m. One vein approximately 2 m wide is parallel to the trend of the canyon, and consists of reddish, fine-grained calcite on the south side and milky white, extremely coarsely crystalline calcite on the north (Fig. 27). One non-vertical vein filled with reddish, fine-grained calcite was found which intersected the bedding obliquely, having about the same strike as bedding but dipping west rather than east.

In the Boquillas Limestone, a few fractures (or possibly faults of small displacement) were found which are completely filled with up to ½ m of large (several centimeter) dogtooth spar calcite crystals. These fractures have a northwesterly trend roughly parallel to faults.

Although only one of the radial canyons in the Solitario rim was actually walked, the presence of veins in the canyon bottom, many of which parallel the canyon, supports origin and control of the canyons by radial fractures associated with the uplift of the Solitario. Corry (1972) reports radial faults associated with uplift at three places in the Solitario rim, one of which is in the Lefthand Shutup. The fact that filled fractures seem to be restricted to the east flank of the Solitario suggests that the filling of fractures was associated with hydrothermal activity, which also was restricted to that area.

Structural History

The Solitario was raised by igneous intrusion in Middle Eocene time, and developed radial fractures and faults on its flanks. The area was uplifted and folded into broad, northwest-trending folds toward the end of the Laramide orogeny. The Terlingua-Solitario anticline probably formed along with other Laramide folds, in a compressional stress field with the maximum principal stress oriented northeasterly. A trap-door dome and other igneous-related structures in surrounding areas were raised during a subsequent period of intrusion after the compressional

Fig. 27. Vein about 2 m wide in Santa Elena Limestone in floor of a canyon of the rim of the Solitario, southeast of Hill 4473 (NW). The vein is parallel to the trend of the canyon, and consists of reddish fine-grained calcite on the south side and milky white, extremely coarsely crystalline calcite on the north. View is to the west.

stress field had relaxed and become extensional across the broad area that was to include the sunken block. With reorientation of principal stress directions so that the least principal stress was northeasterly, Basin-Range faulting began about 22 m. y. ago or less. Northwest-trending, near-vertical normal faults in the quadrangle were mostly downthrown to the northeast, reflecting the position of the quadrangle at the western edge of the sunken block. On the northeast flank of the Terlingua-Solitario anticline, differential movement within fault blocks created two sets of intersecting grabens and horsts in Santa Elena Limestone, and associated drape folding took place in overlying formations. Present erosion and stream dissection proceeded with later regional uplift.

ECONOMIC GEOLOGY

Water

There are no natural bodies of standing water in the quadrangle except for the few relatively large tinajas that persist in the bed of Terlingua Creek. The infrequent, torrential rains mostly become runoff, therefore catchment tanks have been constructed to collect water for stock.

No water wells are known. A few small springs are shown on the Emory Peak (1:250,000) sheet: two in Saltgrass Draw to the southwest, one about two kilometers south of Black Ridge, and one two kilometers west of Black Ridge; but these probably do not flow year round. The Agua Fria spring, to the north of the quadrangle on the Agua Fria Ranch, is the only large source of potable spring water in the vicinity. It runs continuously even during the driest years. The spring, at the west end of Agua Fria Mountain, is fed by rainwater that falls on top of the mountain and filters through the rhyolite intrusive, to emerge at a fault contact between the rhyolite and an upfaulted sliver of Aguja Sandstone (Moon, 1953). Most of the water that is kept in metal tanks by the few Terlingua Ranch land-owners who have erected dwelling structures in the quadrangle comes from this spring, and is purchased from and hauled in by Billy Pat McKinney, lessee of Agua Fria Ranch.

Construction Material

Boquillas flaggy limestone has been used locally for building stone, usually in combination with adobe bricks made with bentonite of the Pruett Formation, and concrete. The Boquillas is yet to be actively quarried, and has been used in the construction of only one building in the quadrangle, south of Black Ridge.

Of possible value in ornamental masonry are the abundant, well-rounded, flat pebbles and cobbles of Comanchean limestone in the basal conglomerate of the Pruett Formation. The conglomerate is yet to be exploited, and is more extensive in the Agua Fria Quadrangle, but is abundant in the Pruett outlier northeast of Black Ridge (Plate I).

Ranching

The extreme northern part of the quadrangle is a part of Agua Fria Ranch, which runs cattle. The remainder of the quadrangle was formerly ranch land, before being purchased and subdivided by Terlingua Ranch.

Land Sales

Most of the quadrangle is owned by Terlingua Ranch, and has been subdivided into plots for sale to the public. Almost all of the five thousand 10-acre (±) plots composing Terlingua Ranch have already been sold to private owners. The ranch operates a lodge with cabins and cafeteria northwest of the Rosillos Mountains, to the east.

Ore Deposits

Though commercially exploitable ores have been mined in adjacent areas, none has yet been found in the Yellow Hill Quadrangle. Cinnabar has been mined at several places in the Terlingua district to the southeast, on the southeast flank of the Terlingua-Solitario anticline, and farther to the southeast in Study Butte. A possible prospect (unmapped) was found in the southwest corner of the quadrangle where hematite, calcite and clay are concentrated in a reddish deposit along the Santa Elena-Del Rio contact, just as cinnabar is concentrated along this contact in some places to the south.

Fluorspar is now being mined by D & F Minerals in the Christmas Mountains to the east, and some was reportedly found by Pioneer Nuclear geologists along contact zones of intrusive bodies between the eastern boundary of the quadrangle and Texas Highway 118 (Ed Huskinson, personal communication, 1974). These fluorspar occurrences, as well as the cinnabar in Study Butte, are associated with rhyolitic intrusives. The almost total lack of such igneous bodies in the Yellow Hill Quadrangle may account for the lack of fluorspar and cinnabar ores.

Some prospecting and drilling for uranium deposits has been done by Conoco and AGIP in the Agua Fria Quadrangle. Uranium exploration has been restricted to the Pruett Formation, which is scarce in the Yellow Hill Quadrangle.

A reported gold prospect on the northeast flank of the Solitario, just outside the northwest corner of the quadrangle, is probably situated at the western contact between a rhyolite vent (Plate I) and the Santa Elena Limestone. There reportedly have been other prospects on the east flank of the Solitario; some of them may have been the copper prospects in the Solitario mentioned by Baker (1935).

Petroleum

So far as I can determine no drilling for oil has been attempted in the quadrangle. A few wells were reported to have been drilled in the Solitario to the west, but were dry holes. Paleozoic rocks of the Ouachita system exposed in the Solitario consist of shale, chert, and cherty limestone, and should be unfavorable for petroleum occurrence. The lack of sandstone in the Cretaceous below the Aguja, plus the fact that Cretaceous limestones are mostly wackestones, makes the rest of the subsurface section unfavorable, unless there are local sites of solution and fracturing, or local packstone, grainstone or reef facies. Even if potential reservoir rocks are present in the subsurface, there are probably few suitable traps.

Wax

The candelilla plant (*Euphorbia antisyphilitica*) is locally abundant and could produce significant quantities of wax if fully exploited. A wax camp in a wind gap between two diabase sill outliers, east of Hill 3215 (EC) reportedly was operated by Mexican nationals at least as recently as the mid-1950's. There are probably other abandoned wax camps as well.

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PLATE I

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

YELLOW HILL QUADRANGLE
TEXAS–BREWSTER CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS, and International Boundary and Water Commission

Topography by photogrammetric methods from aerial photographs taken 1970. Field checked 1971

Projection and 10,000-foot grid ticks: Texas coordinate system, south central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 13
1927 North American datum

UTM GRID AND 1971 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface — Light-duty road, hard or improved surface
Secondary highway, hard surface — Unimproved road
Interstate Route — U. S. Route — State Route

GEOLOGIC MAP OF YELLOW HILL QUADRANGLE

WITH STRUCTURE SECTIONS

Geology by R. P. McCULLOH, 1974 and 1975

YELLOW HILL, TEX.
N2922.5—W10337.5/7.5
1971
AMS 5242 I NW—SERIES V882

EXPLANATION

TIME-STRATIGRAPHIC UNITS (SYSTEM, SERIES) — LITHOSTRATIGRAPHIC AND BIOSTRATIGRAPHIC UNITS

QUATERNARY
Qal — Quaternary Alluvium

UNCONFORMITY

TERTIARY — Oligocene, Eocene — Buck Hill Group
Tmm — Mitchell Mesa Tuff
Tp — Pruett Formation

UNCONFORMITY

CRETACEOUS — Gulfian — Terlingua Group
Kp — Pen Formation
Kbo — Boquillas Formation; ‹‹‹‹ *Allocrioceras* Zone

CRETACEOUS — Comanchean — Washita Group
Kbu — Buda Limestone
Kdr — Del Rio Clay
Kse — Santa Elena Limestone
Ksp — Sue Peaks Formation

Fredericksburg Group
Kdc — Del Carmen Limestone
Ktc — Telephone Canyon Formation

Trinity Group
Kgr — Glen Rose Limestone

Ti — Tertiary Intrusive Igneous Rock; Tid, diabase (mostly sills); Tidr, red hydrothermally-altered diabase; Tidy, yellow hydrothermally-altered diabase; Tidb, brown hydrothermally-altered diabase; Tibv, basaltic vent agglomerate in diabase; Tir, rhyolite; Tias?, analcite syenite?

Tcb — Chert Breccia

Contact, dashed where approximate

Normal Fault
U, upthrown side; D, downthrown side; dashed where inferred, dotted where concealed

Anticline, showing plunge

Syncline, showing plunge

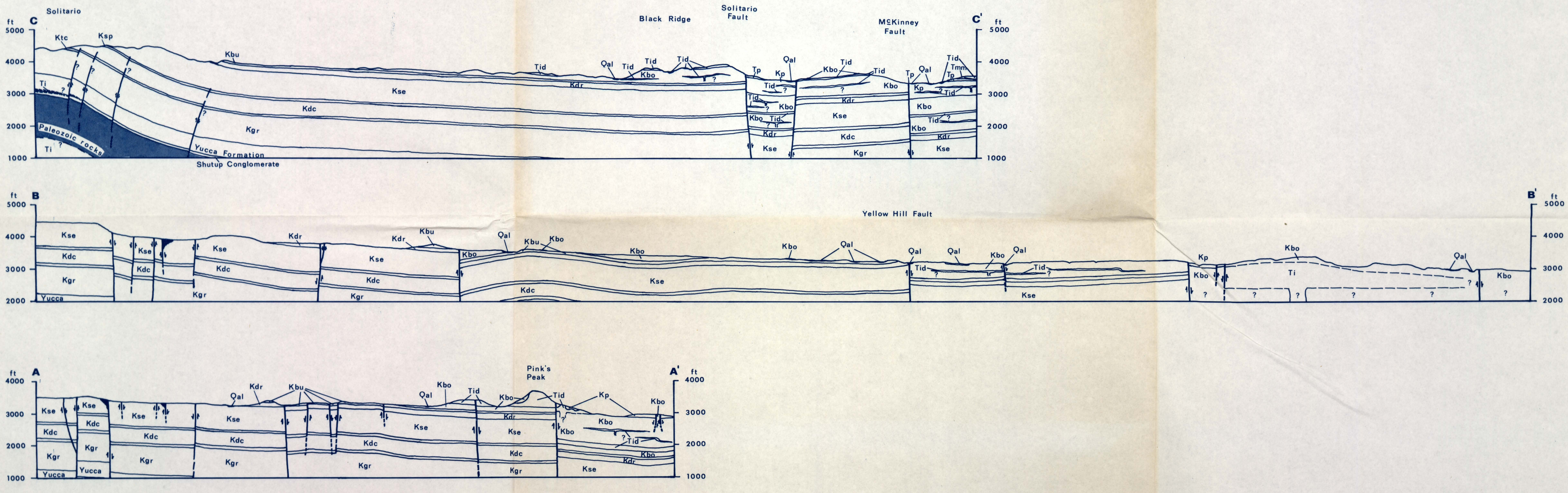
Strike and dip of bedding

Strike of vertical beds

Horizontal beds

Line of measured section

Location of diabase sampled for chemical analysis, K-Ar date



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLATE II

NEW TERLINGUA RANCH ACCESS ROADS

Compiled from Terlingua Ranch Road Maps made by Urban Engineering, Corpus Christi, Texas

YELLOW HILL QUADRANGLE
TEXAS—BREWSTER CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

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