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Geology of Agua Fria Quadrangle, Brewster County, Texas

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ABSTRACT

The 15-minute Agua Fria quadrangle in southwestern Brewster County, Texas, is arid, sparsely vegetated, and includes diverse topographic features that result chiefly from complex structure and variation in rock resistance to erosion. The mountainous and more complicated southern part of the area has suffered much deformation by igneous intrusions and faulting.

The Comanche series is represented by the Devils River limestone, Grayson marl, and Buda limestone. A disconformity separates it from the overlying gradational Gulf series which consists of the Boquillas, Terlingua, and Aguja formations. Because the Boquillas-Terlingua boundary problem is critical and unsettled, lithologic members and paleontologic zones in that section are described in considerable detail. A distinctive 50-foot rock unit, herein named the Fizzle Flat lentil, occurs about the middle of the Boquillas-Terlingua sequence. A widespread angular unconformity separates the Gulf series from the Tertiary Buck Hill volcanic series. Quaternary terrace gravels occur at different levels, and other alluvial deposits have been mapped.

The Tertiary hypabyssal igneous rocks are alkalic and form stocks, laccoliths, plugs, sills, dikes, and bysmaliths or trap-door domes. Several lava flows are preserved in the southwest part of the quadrangle. Metamorphic effects generally are slight.

The area is part of the Big Bend sunken block. Except where influenced by intrusive masses, a pattern of northwesterly normal faults establishes the structural trend of the area. Step faults are common. Most of the major faults are downthrown to the southwest with the huge intervening blocks tilted gently to the northeast. That much of the fault pattern was established during the Laramide revolution and that faulting recurred along the old lines of weakness fairly late in Tertiary time are postulated.

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INTRODUCTION

The 15-minute Agua Fria quadrangle, an area of about 275 square miles in the southwestern part of Brewster County in the Big Bend region of Texas, is bounded by the 29°45′ and 29°30′ parallels and the 103°30′ and 103°45′ meridians (Fig. 1). The center of the quadrangle lies almost 60 miles south of the city of Alpine.

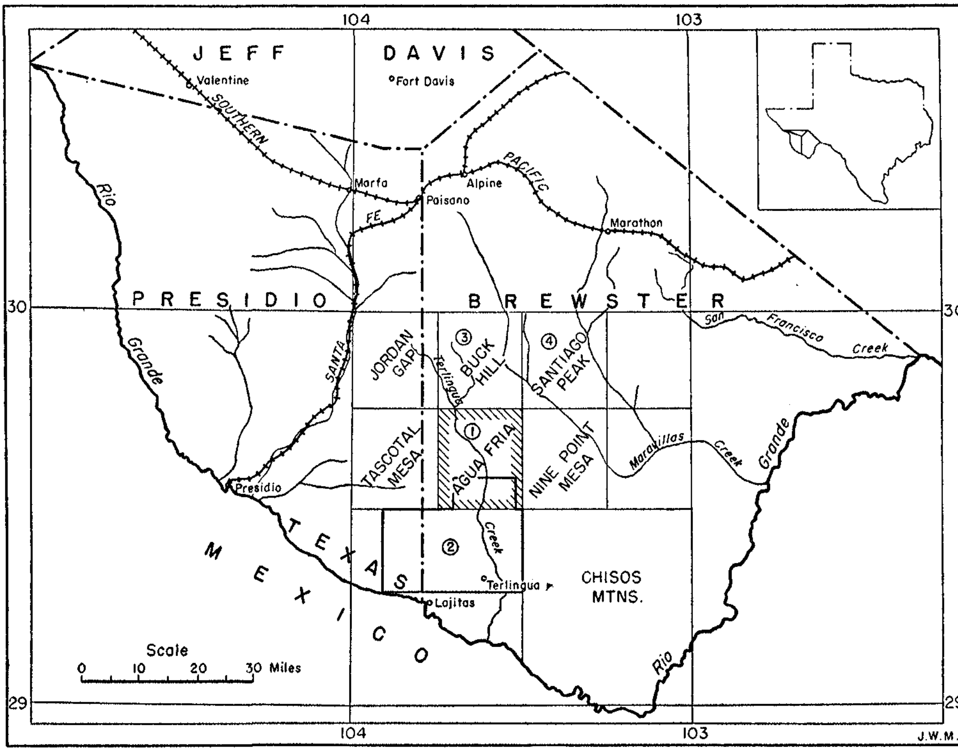

FIGURE 1.—INDEX MAP OF THE SOUTHERN PART OF TRANS-PECOS TEXAS
Showing Agua Fria quadrangle (1) and adjoining areas of published maps: (2) Terlingua-Solitario region (Lonsdale, 1940): (3) Buck Hill quadrangle (Goldich and Elms, 1949); (4) Santiago Peak quadrangle (Eifler, 1943).

The area is arid and devoted to grazing. State highway No. 118, known as the Alpine-Terlingua road, traverses the eastern part of the quadrangle. There are few other good roads, but passable automobile trails have been bladed into remote ranch localities.

The investigation of the structure, stratigraphy, and igneous geology of the Agua Fria quadrangle is part of the large-scale mapping project and program of study that the Bureau of Economic Geology is conducting in west Texas.

FIELD WORK

Field time, during 1947 and 1948, totalled 5 months. The geological data were recorded on aerial photographs and transferred to the U. S. Geological Survey topographic sheet of the Agua Fria quadrangle.

ACKNOWLEDGMENTS

Credit is due so many individuals and organizations that only brief acknowledgments are given here, and others appear in the text.

Dr. John T. Lonsdale, Director of the Bureau of Economic Geology, suggested the problem and directed the work, and Dr. S. S. Goldich supervised the field program. Dr. L. W. Stephenson of the U. S. Geological Survey spent the month of August 1948 in the Big Bend region. His paleontological work was of material value in problems of stratigraphy. Faculty members of the Geology and Petroleum Engineering Departments of The University of Texas and staff members of the Bureau made helpful suggestions and read and criticized the manuscript. Dr. J. A. Wilson identified the vertebrate material.

Robert B. Davis, J. Don Langston, and Mrs. Jule J. Moon were capable assistants, and the advice and cooperation of the ranchers expedited the field work.

Field and laboratory expenses were defrayed by the Bureau of Economic Geology and the Humble Oil and Refining Company Fellowship in Geology.

PREVIOUS WORK

Hill (1900, p. 2) first listed the Trans-Pecos Province as a natural subdivision of the physical geography of the State. Udden (1907b) was the first to describe the stratigraphy. Where possible to determine, his definitions of formations in the Gulf series were followed in the present mapping.

Baker has published several papers on Trans-Pecos Texas that emphasize structure. Many data from his earlier works are included in his publications of 1935.

Lonsdale (1940), the first to concentrate attention on specific rock masses within the quadrangle, studied and mapped the igneous geology of the southern part of the area.

The Buck Hill volcanic series, defined by Goldich and Elms (1949) in the next quadrangle to the north, has been traced in the present work along the western third of the area.

PHYSIOGRAPHY

Great diversity in structural conditions and resistance of the rocks (clays to igneous types) and scant vegetation in this semidesert region provide a variety of topographic forms (Pl. 3; Pl. 4, fig. 1) ranging from valley flats to peaked mountains. The less spectacular features are generally found in the north; those resulting from more complex geological conditions are abundant in the south. The maximum relief, east of Agua Fria Mountain, is almost 1800 feet; the average elevation for the quadrangle is approximately 3500 feet.

Except for the extreme eastern part, where intermittent drainage is into Nine Point Draw, the Agua Fria area is drained by Terlingua Creek and its tributaries, the largest being Alamo de Cesario Creek. Terlingua Creek, which empties into the Rio Grande, is a large intermittent stream with a few permanent stretches and water-holes. The valley developed by it, depending upon rock erosional resistance, ranges from a broad open type to canyons and gorges. Several stream terraces occur along its course in the central part of the quadrangle.

STRATIGRAPHY

Stratigraphic units

Quaternary		**Alluvium**
		Gravel
Tertiary		**Buck Hill volcanic series**
Cretaceous	**Gulf series**	**Aguja sandstone**
		upper Boquillas - Terlingua unit
		lower Boquillas - Terlingua unit
	Comanche series	**Buda limestone**
		Grayson (Del Rio) marl
		upper Devils River (= Georgetown) limestone

Comanche Series

Devils River limestone.—The Devils River limestone was named by Udden (1907a, p. 56–60) from exposures along Devils River in west Texas, where the section consists of resistant, white to gray, massively bedded limestone. These moderately coarse-grained to compact limestones are equivalent to the Edwards and Georgetown formations of central Texas. The upper Devils River is the oldest rock exposed in the Agua Fria area, and fossils indicate that it is of Georgetown age.

OUTCROP: The Devils River limestone crops out on Gray Hill, Packsaddle Mountain, Panther Mountain, and the northeast flank of the Solitario in the extreme southwest corner of the area. These localities are structural highs with many faults of large displacement, and the resistant Devils River forms dip-slopes in the uplifts. At Gray Hill, the dip-slope is to the north-northwest; at Panther Mountain it is south-southeast; in the Solitario area, to the northeast; and on Packsaddle Mountain it is very nearly quaquaversal. Fault scarps of the Devils River form precipitous cliffs in which are caves and shelters.

At Gray Hill and at Panther Mountain the Devils River is exposed in trap-door blocks of domical uplifts. Outcrops in the southwest part of the area occur in similar up-faulted blocks. The upper Devils River limestone at Packsaddle Mountain wraps around a rhyolite plug except on the north flank, where a fault of great magnitude interrupts its continuity.

THICKNESS AND LITHOLOGY: The greatest observed thickness of Devils River section is on the west side of the igneous plug that forms the core of Packsaddle Mountain, but complex structural conditions made a measurement impractical. Hence only the 180 feet of upper Devils River exposed at the south end of Gray Hill is described.

The lower 120 feet of this interval consists of very hard, gray to brownish-gray, massively bedded, almost pure limestone with a few zones of gray to rusty brown chert nodules. The massive beds form vertical cliffs, some of which are honeycombed to cavernous. The strata exhibit karren and a type of weathering which suggests that solution has taken place along minute irregular cracks. The tinahitas described by Udden (1907b, p. 28) characterize the weathered rock surfaces in this section, and the rock weathers into angular fragments.

Evenly bedded limestones 1 to 2 feet in average thickness make up most of the upper 60 feet of Devils River section. These strata are essentially the same color as the massive beds below except for a tendency toward lighter and even whitish shades for the uppermost beds. Being somewhat irregularly bedded, the topmost beds weather to nodules as well as angular fragments. On aerial photographs, a fluted pattern of weathering characterizes the top of the formation.

FOSSILS: Fossils collected from the Devils River on the north flank of Packsaddle Mountain include: *Ennalaster texanus* Roemer, *Holaster simplex* Shumard, *Kingena wacoensis* Roemer, *Gryphaea washitaensis* Hill, *Gryphaea* sp., *Pecten (Neithea) bellula?* Cragin, *Pecten (Neithea) texanus* Roemer, *Pecten* sp., a small *Nucula*-like pelecypod, and a small *Hamites*. At the top of the Devils River section on Gray Hill several large *Turrilites brazoensis* Roemer were found. Although some of the species listed have longer ranges, several are Georgetown fossils. Paleontologic evidence supports, therefore, the assignment of Georgetown age to the Devils River beds exposed in the area.

STRATIGRAPHIC RELATIONS: The contact of the Devils River limestone with the overlying Grayson marl is conformable. The base of the Devils River is not exposed in the Agua Fria quadrangle.

Grayson (Del Rio) Marl.—Cragin (1894, p. 40, 43) first used the term Grayson marl for numerous outcrops, especially in Grayson County, Texas, of the yellowish, highly calcareous, slightly arenaceous, fossiliferous marl that contains abundant *Exogyra arietina* Roemer. Hill and Vaughan (1898, p. 236) applied the name Del Rio clay to the greenish laminated clay, which weathers yellow and includes beds of limestone, in the vicinity of Del Rio, Val Verde County, Texas. Here the clay is underlain by Georgetown limestone and overlain by Buda limestone. Although the definition of Hill and Vaughan is more specific and fits precisely the stratigraphic sequence of the Agua Fria area, Cragin's Grayson has priority.

OUTCROP: Sandwiched between the massive limestones of the Devils River below and the Buda above, the Grayson marl crops out in the four uplifts listed for the Devils River formation. The uppermost Grayson is exposed at a fifth locality about 2 miles east-southeast of the Old Stage Stand (NE)[1] in the upthrown block of a fault of the same name.

THICKNESS AND LITHOLOGY: A 118-foot thick

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[1] To aid in locating positions on Plate 1, the following scheme is used:

NW	NC	NE
WC	C	EC
SW	SC	SE

The Old Stage Stand (NE), for example, is found in the northeast 5-minute quadrangle of the map area.

Grayson section was measured on Gray Hill, but badly covered slopes prevented the exact determination of vertical positions of fossil zones.

The Grayson formation consists of friable, yellow-green-gray, laminated calcareous shale to massive calcareous clay or marl. The lower third of the section contains a few thin, rusty silt beds up to 2 inches thick. In the upper part, there are thin beds of impure (sandy), rusty brown limestone that contain countless *Haplostiche texana* (Conrad). A 2.5 to 3-inch bed of hard, rusty yellow-gray coquina, composed of tightly cemented fragments of oyster shells, occurs a foot below the Grayson-Buda contact.

Talus and slide rock conceal all except the uppermost part of the Grayson formation at the base of the fault scarp about 2 miles east of the Old Stage Stand. Laminated beds of hard, rusty brown, silty to sandy limestone, 3–6 inches thick, make up this section.

FOSSILS: *Exogyra arietina* Roemer, abundant in the middle Grayson of central Texas, is rare in the Agua Fria area. The diagnostic Grayson fossil in west Texas is the arenaceous foraminifer *Haplostiche texana* (Conrad), abundant in the upper sandy limestone beds.

Turrilites brazoensis Roemer and the oysters *Exogyra cartledgei* Bose and *Gryphaea mucronata* Gabb occur both above and below the Grayson-Buda contact. Other fossils found near the top of the Grayson section on Gray Hill are *Ennalaster texanus* (Roemer) and a *Gryphaea* similar to *G. washitaensis*.

STRATIGRAPHIC RELATIONS: Although the two formations differ markedly lithologically, no indication of unconformable relationships between the Grayson and the Devils River was noted. There is a thin transition zone in which the almost pure limestone of the Devils River grades upward into impure, marly, nodular limestone, and this grades into typical Grayson marly facies. The presence of *Turrilites brazoensis* Roemer in both upper Devils River and lower Grayson adds support to the evidence for a conformable contact.

Possible bore-holes and the oyster shell coquina near the top of the Grayson suggest a submarine break in sedimentation at the end of Grayson time.

Composite section of Comanche Cretaceous measured on Gray Hill from south to north and beginning east of north-south fence line

	Thickness *Feet*
Gulf Cretaceous	
Boquillas flags—	
11. Hard, gray to rusty red, thin-bedded and banded lower Boquillas flags of impure silty limestone with gritty feel. Flags weather to angular fragments. Thick growth of lechuguilla....................	2
—Disconformity—	
Comanche Cretaceous	
Buda limestone—	
10. Hard, creamy white to light-gray, unevenly bedded, relatively pure porcellaneous and brecciated limestone. Decrease in bed thickness from base to top. Uppermost strata 1.5–0.5 foot thick. Thin marly breaks and irregular nodules................................	69
—Diastem?—	
Grayson marl—	
9. Friable, yellow-green-gray, laminated to massive calcareous shales and clays. Several thin rusty silt beds, up to 2 inches thick, near base. Thin beds of impure rusty brown limestone plus innumerable *Haplostiche texana* (Conrad) in upper section. Hard, rusty yellow-gray coquina bed 2.5–3 inches thick, including specimens of *Exogyra* and *Gryphaea*, 1 foot below Buda contact. Internal molds of bore-holes (?) in top few inches.........	118
Devils River limestone—	
8. Resistant, gray to white limestone. Most of lower beds 1–2 feet thick with tendency toward more irregular bedding, lighter color, and nodular weathering upward. *Pecten* spp., *Kingena wacoensis* Roemer, and snail-like gastropods common	60
7. Two very hard limestone beds, each 1 foot thick, mark top of vertical cliff-forming section........................	2
6. Lithologically similar to unit below except cavernous, less honeycombed, and generally fewer fossils. Well-developed karren and fossil agglomerate mark top	

of this massive section. Chert zone with nodules up to 8 inches in diameter 18 feet above base of unit. Ocotillo and creosote bush common................ 51

5. Very hard, light-gray to brownish-gray, massively bedded, somewhat honeycombed limestone. Highly fossiliferous: silicified rudistids and a few *Pecten*..... 20

4. Very hard, light-gray to brownish-gray, very massively bedded, slightly honeycombed limestone. Two rather indistinct horizons marked by gray to rusty brown chert nodules up to 1.5 feet in diameter occur 4 and 6 feet above base of interval. Silicified fossils and more pronounced honeycombing in upper 9 feet. Karren weathering...................... 17

3. Partly covered, very hard, gray, massively bedded limestone with karren and cracked weathering. Silicified fossils..... 30

2. Slope-covered interval of Devils River. . 100

1. East-west road in valley flat.

Total upper Devils River exposed.. 180

Buda limestone.—Vaughan (1900, p. 18) substituted the name Buda limestone for the preoccupied Shoal Creek limestone as defined by Hill in 1889. At the type locality along Shoal Creek in Austin, Texas, the formation consists of hard, white to yellow, unevenly bedded, nodular limestone which oxidizes to darker yellowish or pinkish shades because of its glauconite content. The Buda, named after a hamlet in Hays County, is the top formation of the Comanche series. At Austin, where its thickness is 45 feet, the Buda overlies the Del Rio clay and underlies the Eagle Ford shale.

OUTCROP: The Buda limestone occurs at the same five localities listed for the Grayson marl: the Solitario (SW), Panther Mountain (SC), Packsaddle Mountain (SE), Gray Hill (SE), and east of the Old Stage Stand (NE). In each place the more resistant Buda caps the soft Grayson and thereby forms a cuesta or hogback. Precipitous Buda cliffs are common.

Because of the more rapid erosion of the underlying Grayson marl, the base of the Buda characteristically projects as overhanging ledges from which huge rectangular blocks, the result of almost right-angle jointing, become dislodged and come to rest on the more gently sloping Grayson surface. The gaping angular vacancies in the basal Buda plus corresponding cubical limestone blocks lying several feet below form a pattern that makes this contact identifiable even at great distances.

THICKNESS AND LITHOLOGY: The Buda limestone at Gray Hill is 69 feet thick. The section consists of hard, creamy white limestone that weathers to light gray. Irregular bedding accounts for the numerous nodules found as slope material, but a greater percentage of the float rock consists of angular fragments. Fresh outcrops of the limestone appear brecciated, and the disintegration of the brecciated rock masses presumably accounts for many of the angular pieces.

Thicker and somewhat massive beds, which exhibit the irregular bedding within themselves, occur in the lower part of the Buda section; but, in the upper portion, bed thickness decreases to 1.5–0.5 foot. Some marl is associated with the thinner and more unevenly bedded strata. The thicker beds contain little marl and are, according to Adkins (1933, p. 397), "a compact, fine grained 'porcellaneous' facies ... a dense, light-colored limestone with pronounced conchoidal fracture." He further describes the more dense phases as "semi-lithographic".

Lechuguilla grows on the Buda limestone; and, where slopes are not excessively steep, a brush band follows the base. This band stands out rather conspicuously, for vegetation is generally scarce.

FOSSILS: Good identifiable fossils in the Buda are relatively rare, and few were obtained in place. Most specimens were collected on slopes and cannot be assigned to any definite vertical position. A tentative identification of the fossils found on the west flank of Gray Hill follows:

Corals—
- Cladophyllia?
- Solitary hexacoral

Echinoidea—
- *Hemiaster calvini* Clark

Pelecypoda—
- *Pecten (Neithea) subalpina* Böse

Pecten sp.
Internal mold of a pelecypod
Gryphaea mucronata Gabb
Exogyra clarki Shattuck
Gastropoda—
Turritella budaensis Shattuck
Pleurotomaria stantoni Shattuck
Several other unidentifiable gastropods
Cephalopoda—
Budaiceras sp.
Turrilites sp.
Fragment of an ammonite, probably 8–10 inches in diameter, with large straight ribs and prominent offset tubercles

STRATIGRAPHIC RELATIONS: The Grayson-Buda contact is sharp and apparently conformable, yet certain evidence suggests a hiatus at the top of the Grayson marl. Preserved in basal Buda limestone are possible internal molds of bore-holes up to 2 inches in diameter. The top of the Grayson appears to have been riddled with compound bore-holes before the deposition of the Buda, for the fucoidlike molds are crowded and intersecting. The Buda material that filled the tubes is clastic limestone with many shell fragments, some quite large. If these sedimentary features are true bore-holes, they are the horizontal variety, for none was found that projects more than a few inches down into the Grayson. That the casts are elliptical in cross section with the long axis parallel to the bedding suggests some settling after the tubes were made. Huge overturned blocks of fossiliferous basal Buda afford good exposures of the fucoidal bore-hole fillings.

There is no evidence for a disconformity at this contact in central Texas. If west Texas experienced a break in sedimentation, probably the hiatus represents only a submarine diastem.

A definite break occurs at the top of the Buda, for everywhere the contact with the overlying Boquillas flags is decidedly sharp. According to F. L. Whitney (personal communication): "So far as is really known, no species of the Comanche occurs in the Gulf." The abrupt lithological change at this contact plus the gentle undulations of the top of the Buda suggest a disconformity.

Gulf Series

Tentative correlation.—The following tentative and generalized regional correlations introduce the Gulf series stratigraphy of the Agua Fria quadrangle:

Agua Fria area	Central Texas
Aguja	Taylor
Upper Boquillas-Terlingua unit (= Terlingua ±)	Austin
Lower Boquillas-Terlingua unit (= Boquillas ±)	Eagle Ford

Because of gradational contacts, insufficiently detailed paleontological work in the Trans-Pecos region, and vague definitions of formational boundaries, the Gulf series of the area presents many stratigraphic problems. The most critical problem arises in the Boquillas-Terlingua sequence.

The Boquillas-Terlingua Problem.—Udden (1907b, p. 29–33) applied the name Boquillas flags to the basal formation of the Gulf series which, in the Chisos country, immediately overlies the Buda limestone and grades into the overlying Terlingua beds. The flaggy limestone strata he described are fossiliferous, thin bedded, sandy in places, have closely spaced joints, and are separated by delicate seams which may not appear on freshly exposed surfaces. A chalky texture characterizes the upper 100 feet of his Boquillas formation. The rocks are ordinarily cream grayish-white, but faint ferruginous red stains occur, and in some areas certain ledges are dark and almost black on fresh fractures. Udden gave a thickness of 585 feet to this western equivalent of the Eagle Ford shales. The type locality is in the vicinity of Boquillas [Hot Springs?] post office on Tornillo Creek in the Chisos Mountains quadrangle, Brewster County, Texas, about 40 miles southeast of the Agua Fria quadrangle.

Udden (1907b, p. 33–41) applied the name Terlingua beds to the yellowish-white, indurated, stratified chalk that gradually changes upward to an impure gray marl, which becomes less and less calcareous until it is a true clay. The uppermost clays contain some thin layers of concretionary limestone and calcareous sandstone. Both lower and upper Terlingua contacts are gradational. The formation rests on the Boquillas flags, and the Aguja sandstone overlies it. Udden correlated the Terlingua with the Austin chalk and Taylor marl of the central part of the State. He assigned a thickness of 1250 feet to these beds and named them for exposures along Terlingua Creek in the Terlingua quadrangle, Brewster County, Texas.

Several new terms, though undefined at this point, are introduced in Figure 2. The problem, stated briefly, is: The Boquillas-Terlingua contact lies somewhere within the 300 feet of gradational strata between the *"Crioceras"* zone and the *Inoceramus undulato-plicatus* zone. The *"Crioceras"* zone is the uppermost clearly recognizable fossil zone with presently known unquestionable Eagle Ford fossils. The *Inoceramus undulato-plicatus* zone is the lowermost clearly recognizable fossil zone with presently known unquestionable Austin fossils.

Analysis of Udden's several definitions of the Boquillas and Terlingua led to the conclusion that the Fizzle Flat lentil of the Agua Fria area (Fig. 2) occupies a stratigraphic position fairly close to his intended Boquillas-Terlingua boundary. To avoid adding further to the confusion partly caused by the inexact nature of Udden's definitions, no attempt was made to show either the Boquillas formation or the Terlingua formation as such on the geologic map (Pl. 1). Instead, the Boquillas-Terlingua section was considered an entity, and a lower Boquillas-Terlingua unit (= Boquillas ±) and an upper Boquillas-Terlingua unit (= Terlingua ±) were mapped. In the 300 feet of strata between the *"Crioceras"* zone and the *Inoceramus undulato-plicatus* zone, the contact between the top of the *Austiniceras?* ledge and the base of the Fizzle **Flat** lentil (Fig. 2) is the most easily recognized one over the area as a whole. Consequently the base of the lentil was arbitrarily selected as the boundary between the lower Boquillas-Terlingua unit and the upper Boquillas-Terlingua unit.

Lower Boquillas-Terlingua unit.—Limestone flags of the lower Boquillas-Terlingua unit (= Udden's Boquillas ±) form the most widespread rock outcrops in the Agua Fria quadrangle. Exposures in the northeast portion of the area consist almost exclusively of this unit. Extensive outcrops also occur in the southern part of the area, where positive structures produce isolated patches of the flaggy strata surrounded by late Gulf and Tertiary beds.

THICKNESS AND LITHOLOGY: A continuous section of the lower Boquillas-Terlingua unit could not be found within the quadrangle. However, the sequence from the top of the Buda through the *"Crioceras"* zone is well exposed in the canyon walls of Terlingua Creek at the south boundary of the area. The only interruptions in this section are a dike 12 feet wide and a sill 50 feet thick. Vertical cliffs practically prohibited the collection of fossils from the lower 100 feet of this section.

The middle or critical portion of the Boquillas-Terlingua unit, from the *"Crioceras"* zone through the *Inoceramus undulato-plicatus* zone, is well exposed and quite accessible along the west bank of Terlingua Creek from the mouth of Alamo de Cesario Creek upstream for a distance of half a mile (Pl. 2, fig. 1). This locality is at the western extremity of Half Dome (SC).

The lower Boquillas-Terlingua unit can be conveniently divided into three lithologic units. These, with approximate thicknesses, are:

Upper shaly member..................	100 feet
Middle terraced member.............	205 feet
Lower nodular member.	210 feet

LOWER NODULAR MEMBER: This member, slightly over 210 feet thick, contains hard, irregularly shaped calcareous concretions and nodules. The basal several feet are variable in color; shades of red, brown, yellow, and gray are common. There is also considerable lithological variation. A bed of brownish, indurated, limonitic sandstone, 2 to 3 inches thick, rests on the gently undulating surface of the Buda limestone. Above this, thin and irregularly bedded, impure, sandy limestone flags alternate with 1-inch seams of bentonite, silt, or fine-grained sandstone. These lower banded flags, 1–3 inches thick, appear laminated. Chert is found in some of the lower beds, and fat, disc-shaped calcareous concretions are locally abundant. Sandstone and especially silty shale increase in percentage upward from the basal heterogeneous beds so that the next 100 feet is predominantly rusty brown to dull-gray silty and sandy shale. The shale includes more resistant limestone beds, up to 4 inches thick, that occur at intervals of 4 or 5 feet. Most of the limestone beds contain small limonite nodules.

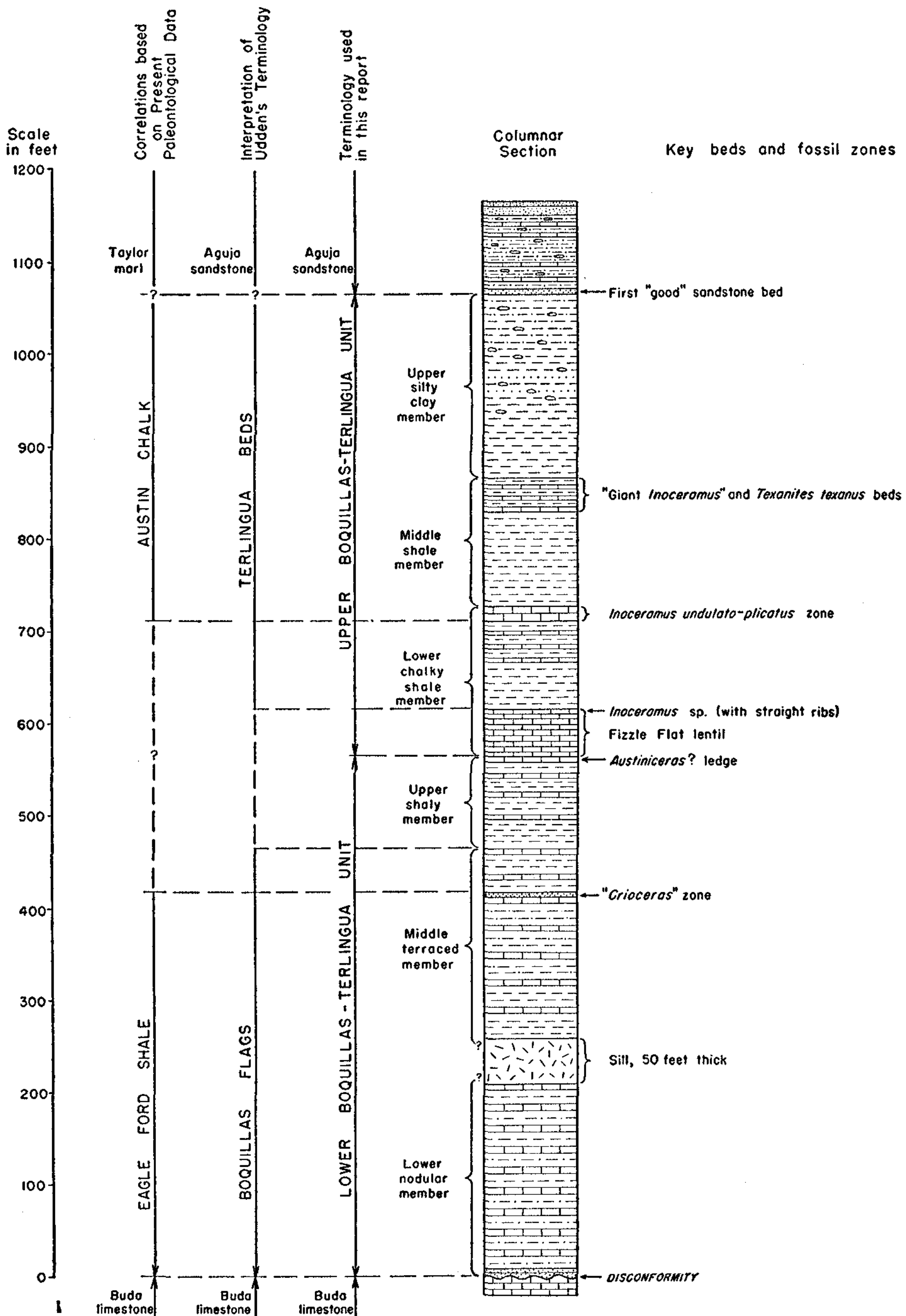

FIGURE 2.—CORRELATION OF GULF SERIES IN AGUA FRIA QUADRANGLE

In the upper 100 feet of the lower nodular member, medium dark-gray, silty to fine-grained sandy shale alternates with impure, cream-gray limestone beds that average a foot in thickness, weather to thin plates, and become more cream-colored upward. Nodules are present both in the shale and as more indurated portions of the limestone beds. This section weathers into vertical cliffs and isolated topographic forms that resemble stacks or chimneys.

MIDDLE TERRACED MEMBER: This unit, more than 200 feet thick, consists of limestone ledges 0.5–1.5 feet thick that alternate with calcareous shale intervals with an average thickness of 3 feet. The alternating hard and soft strata produce erosional terraces, the outstanding characteristic of this member. The terraces are especially well developed along the Alpine-Terlingua road north of the Hale Cabin fault (NE). The more resistant beds average 1 foot thick, and are hard, cream to yellowish-brown, gritty limestone that weathers to thin shale-like laminae. The intervening calcareous shales are indurated, creamy yellow, and silty.

The resistant limestone at the top of this member forms a dip-slope along the south margin of Half Dome (SC). So prominent is this erosional terrace that the middle terraced member and the upper shaly member can be distinguished even with a 50-foot topographic contour interval. The 4-foot thick *"Crioceras"* zone, one of the most important lithologic and paleontologic markers in the entire Gulf series, occurs 50 feet below the top of this member. The zone consists of hard, brown, thin-bedded, sandy limestone with limonitic nodules, white calcite veins, and a distinctive fauna.

Rare color banding is present in the lower portion of this section in the southwestern part of the quadrangle. The color bands, which parallel the bedding planes and average 0.2 inch in thickness, are red, yellow, and white.

UPPER SHALY MEMBER: The top of this member has been chosen arbitrarily as the top of a resistant limestone bed referred to as the *Austiniceras?* ledge, which produces the dip-slopes of many cuestas and hogbacks. At most places the ledge is fairly heavily covered with scrubby vegetation, which contrasts with the overlying vegetation-barren Fizzle Flat lentil. The topography above and below the ledge is decidedly different. In the Fizzle Flat lentil above, a more rounded, curvaceous, gentle, low, and subdued topography prevails; the relief below is harsh and angular with plunge basins and canyons.

The *Austiniceras?* ledge is a hard, creamy yellow to yellowish-brown, silty to fine-grained sandy limestone, one-half to 1 foot thick, that contains abundant *Ostrea congesta* Conrad on its upper surface. Enough detrital silica is present in this stratum to give it a flint-like odor when struck with a hammer.

The 100 feet of section below the *Austiniceras?* ledge consists predominantly of indurated, creamy yellow to gray, silty calcareous shale that weathers to biscuit-shaped nodules. Much of the very thin platy material found in this section is derived from thin silty limestone beds of irregular vertical distribution. Lime content increases upward, and more resistant beds of impure limestone appear in the upper 40 feet of the section.

Section of upper portion of lower Boquillas-Terlingua unit (= upper Boquillas±) measured within half a mile up Terlingua Creek from point near mouth of Alamo de Cesario Creek.

	Thickness *Feet*
Upper Boquillas-Terlingua unit—	
6. Fizzle Flat lentil: Indurated to hard, creamy yellow, platy, impure silty limestone that breaks down into small angular fragments of almost uniform size (up to 2 inches square). Brown clastic dikes and white calcite dikes common. Almost completely barren of vegetation. Blinding glare in bright sunlight. Small *Inoceramus* with alternating large and small concentric undulations and medium-sized *Inoceramus* with large concentric undulations..................	43
Lower Boquillas-Terlingua unit—	
(Top of upper shaly member)	
5. Indurated, creamy-yellow to gray, laminated to platy, silty, calcareous shale. Platy material mostly thin silty limestone beds of irregular vertical distribution. Shale weathers to biscuit-shaped nodules. $CaCO_3$ percentage increases upward. Prominent, impure, platy, and silty limestone ledges containing large inocerami in upper 40 feet. Topmost thick, resistant, overhanging limestone bed (the *Austiniceras?* ledge) characterized by abundance of *Ostrea congesta* Conrad, a few cart-wheel ammonites, and large inocerami. Bed forms vegetation-	

covered dip-slopes; plunge basins and canyons develop in underlying strata.............................. 101.5

(Top of middle terraced member)

4. Similar to unit 2. A dirty brown bed with *Inoceramus labiatus?* Schlotheim and a medium-sized *Inoceramus* with large concentric undulations occurs 18½ feet above *"Crioceras"* zone. Top of this unit forms dip-slopes and erosional terraces.................... 48.5

3. *"Crioceras"* zone: Alternating hard, dirty brown to gray-brown limestone beds of 4 inches average thickness and indurated, brownish-gray, laminated to platy, calcareous, silty shale with very thin and irregular lenses of impure limestone. *Baculites gracilis?* Shumard, *"Crioceras"* sp., *Scaphites?,* a small *Inoceramus* with large concentric undulations, and a small pelecypod........................... 4

2. Hard, creamy yellow, 1-foot thick limestone beds alternate with indurated, creamy yellow, laminated calcareous shale that becomes somewhat silty upward and increases in thickness at expense of limestone beds.............................. 77.5

1. Northwest-southeast fault.

Section of lower Boquillas beginning on west bank of Terlingua Creek just outside south boundary of quadrangle and extending northward toward Hill 3450

Boquillas flags—

10. *"Crioceras"* zone: Hard, rusty brown to brown, evenly bedded and banded impure sandy limestone with numerous small limonitic nodules. Fossils: *"Crioceras," Scaphites, Baculites gracilis?* Shumard...................... 3 to 4

9. Hard, cream-colored limestone beds, 1± foot thick, alternating with shale beds 3 to 4 feet thick. Erosional terraces produce step-like slopes. Section is light-gray creamy yellow........... 134

8. Limestones and shales turned black by contact metamorphism.................. 18

7. Badly altered, dark greenish-gray to black, analcime microsyenogabbro? sill of variable thickness.............. 50±

(Top? of lower nodular member)

6. Alternating, dark-gray, silty to fine-grained sandy shales and 1-foot thick impure cream-gray limestone beds. Numerous calcareous nodules in shales and as more indurated portions of limestone beds. Chimney weathering. One large pseudoceratite found about middle of interval. Limestones become more cream-colored upward. At top, limestone and shale metamorphosed, banded, and weathered into thin plates.................... 100±

5. Dark-gray to black shale zone at middle of which is a 1-foot bed of whitish, impure limestone that weathers into thin plates........................ 10

4. Similar to unit 2. Sandstone and silty shale increase at expense of limestone beds so that section is predominantly rusty brown to dull-gray silty and sandy shales with prominent hard limestone beds, 3 to 4 inches thick, at intervals of 4 or 5 feet. Some limestone ledges are continuous and evenly bedded; others are lenticular; all contain small limonite nodules. Hard calcareous nodules and concretions common. Bentonitic beds, up to 2 inches thick, rare. Vertical cliff.............. 95

3. Bentonite layer.................... 0.3

2. Hard, grayish-brown, somewhat irregularly thin-bedded, flaggy, sandy, banded, impure limestone alternating with seams (average thickness, 1 inch) of bentonite, silt, or fine sandstone. Small, unidentified ammonite, 1+ inch in average diameter, resembles *Scaphites.* Brownish, indurated, limonitic sandstone in basal 2 or 3 inches. 6

—Disconformity—

Buda limestone—

1. Top of hard, white, porcellanous, irregularly bedded, nodular limestone with very gently undulating surface.

Certain special features are peculiar to the lower Boquillas-Terlingua unit at Red Bluff, where unquestionable Boquillas directly overlies an intrusive, and the flags are jet-black for a distance of 40 to 50 feet above the contact. Only slight metamorphic effects were observed near other intrusions, and it seems improbable that so thick a section of dark-colored limestones resulted solely from contact metamorphism. Udden (1907b, p. 31) says that in some areas certain ledges of the Boquillas are dark and almost black on fresh fractures. Perhaps the dark beds occur at Red Bluff by mere coincidence.

Close examination of the black flags reveals that mineralization has taken place high above the igneous-sedimentary contact, because the black rock has a higher density than ordinary Boquillas limestone. Certain strata contain peculiar, almost spherical epigenetic concretions that resemble algal structures and through which bedding planes extend. The sedimentary structures average 0.4 inch in diameter and consist of thin, siliceous shells, inside which the composition apparently approaches the normal Boquillas lithologic character. Slightly darker nuclei are present in some of the concretions, but the limestone outside the shells is black and more highly mineralized.

Although the supposed concretions are epigenetic, probably they were in existence before the Red Bluff intrusion. At the time the magma was injected, mineralization seems to have taken place in those portions of the limestone unprotected by the siliceous shells. Apparently the interiors of the concretions were largely shielded from such mineralization.

Many of the beds in this area have strong petroliferous and sulfurous odors. Perhaps much of the darker color is due to carbonaceous material. At the lower contact of the sill on the south flank of Red Bluff, much of the originally black material appears to have been driven off by heat.

These hard black limestones, like the normal Boquillas beds, weather to angular fragments. Some ledges are so brittle that they shatter easily when struck with a hammer.

Reddish patches are common in the Boquillas on the northeast flank of the Solitario (SW). Because these are near intrusive masses, it is assumed that they resulted from igneous activity and indicate mineralization.

FOSSILS: The lower Boquillas-Terlingua unit is generally quite fossiliferous; pelecypods and ammonites are most abundant. Poor preservation, due largely to fragility of the original shell material, frequently makes accurate determinations of species, and even genera, impossible. This applies particularly to several species of *Inoceramus,* which are present throughout the flaggy unit. The fauna is summarized from base to top.

Inoceramus labiatus Schlotheim is the most common fossil in the lower Boquillas-Terlingua and apparently ranges throughout the entire unit.

A small, unidentified ammonite, 1+ inch in average diameter, which resembles *Scapkites,* occurs 6 feet above the Buda contact.

A large pseudoceratite with only one small secondary saddle in the first lateral lobe was found about 50 feet below the top of the lower nodular member.

Twenty-five feet below the base of the *"Crioceras"* zone is a small, elliptical, ribbed *Inoceramus* (length, 1¼ inches; height, 1 inch). On this specimen, the concentric undulations are very fine and numerous, and the radiating ribs are comparatively coarse.

The hard, brown, sandy limestone beds which make up the 4-foot *"Crioceras"* zone contain several genera and species, and practically all specimens are filled with clear calcite crystals. These fossils, in order of decreasing abundance, are:

"Crioceras" sp.
Baculites gracilis Shumard
Scaphites sp.
Inoceramus labiatus Schlotheim
Inoceramus sp. (3+ inches in diameter)
Acanthoceras?

A *Prionotropis woolgari?* (Mantell), 9 inches in diameter, was found in the bed of a creek 2 miles west of Dewees Tank (NE). The stratigraphic position is near the top of the middle terraced member.

Several genera and species are found in the *Austiniceras?* ledge, a white, chalky limestone bed about 4 feet in average thickness. The ledge is named from one poorly preserved cart-wheel ammonite which Adkins has seen and believes is *Austiniceras,* a Turonian form. The specimen, an internal mold, is a thin, evolute, sharp-keeled ammoniticone, 28 inches in diameter, with an imperfectly preserved, complicated suture. The form consists of four whorls; the maximum width of the living chamber is 2.5 inches, and its height is 1 foot. Gayle Scott (1926, p. 100) stated: "At the top [of the Eagle Ford], one finds . . . some carinate ammonites which, up to the present, have not been described. . .." Adkins (1933, p. 431) wrote that the Boquillas flagstones ". .. contain near the top *Scaphites, Prionotropis,* a three-foot ammonite, *Inoceramus* cf. *labiatus* and other fossils. . .." Perhaps Scott and Adkins referred to some such *Austiniceras?* form. If so, this suggests that the Boquillas-Terlingua contact is at the top of or somewhere above the *Austiniceras?* ledge.

Ostrea congesta (Conrad) Hall, although having a much greater vertical range, is characteristic of the *Austiniceras?* ledge. The upper surface of the bed is normally completely covered with these small oysters.

A poorly preserved ammonite, about 1 foot in diameter, is possibly a compressed *Prionotropis eaglensis* Adkins. Other smaller ammonites, 2 to 3 inches in diameter, were also noted in this ledge.

Several species of *Inoceramus* occur in the *Austiniceras?* ledge. One is *Inoceramus labiatus?* Schlotheim. Another larger form averages a foot across and has large concentric undulations on which fine rugae are superimposed. Possibly the ribbed species of *Inoceramus* collected by Stephenson from the top of the Fizzle Flat lentil occurs in this ledge.

A species of *Inoceramus,* which may be new, was found at the top of the *Austiniceras?* ledge. The internal molds range up to 1 ± foot across but are ordinarily about the size of a person's hand. The over-all shape is that of a fan, and the angle at the terminal beak is acute. The concentric undulations are diagnostic; most are highly raised and fairly sharp, but a few are low and well-rounded. Radiating from the beak toward the ventral margin of the shell for a little more than a third of the distance are several fairly well-developed ribs, which are neither as prominent nor as distinct as the undulations. This ribbed specimen is similar to but may not be the same as the species found by Stephenson at the top of the Fizzle Flat lentil.

Collected at random from Boquillas outcrops in the southwest part of the area were *Inoceramus labiatus* Schlotheim; a thin, discoidal ammonite, 2¼ inches in diameter, which may be *Placenticeras;* and a very small, evolute ammonite, half an inch in diameter, which consists of five whorls ornamented by numerous strong ribs.

STRATIGRAPHIC RELATIONS: Contact of the Boquillas with the underlying Buda limestone offers no problem, for a clear-cut break separates these two formations of different composition. The question always arises, however, as to whether this contact is disconformable. The gently undulating upper surface of the Buda, the sharp change in lithology, and the sandy basal few feet of the Boquillas suggest a hiatus. Perhaps the only erosion that took place at the close of Buda time was that caused by submarine currents, but there was certainly a break in sedimentation. Fossil evidence supports this conclusion, for Comanche and Gulf species are not found above and below the contact, respectively.

The Boquillas and the overlying Terlingua intergrade.

Upper Boquillas-Terlingua unit.—The upper Boquillas-Terlingua unit crops out extensively in the central portion of the south half of the mapped area. Owing to faults and talus slopes, a complete section suitable for measurement could not be found. The described section is compiled from measurements made from fossil zone to fossil zone at different localities.

The best and most accessible exposures of the lower part of the section, including the debated Boquillas-Terlingua contact, are in the Fizzle Flat fault block west, south, and southeast of Clanton ranch (C).

Fair exposures of the upper part of the upper Boquillas-Terlingua unit occur east of Agua Fria Mountain; talus is a problem, but the uppermost beds are not seriously interrupted by faults.

The map shows a complete upper Boquillas-Terlingua section southwest of north Pitahaya Hill (SC). This section is suitable for a detailed study of the lower beds; but it seems that concealed faulting, perhaps with a northwest-southeast trend, has disturbed the Terlingua beds just below the Aguja. These unfavorable conditions discouraged the measurement of a section here.

THICKNESS AND LITHOLOGY: The upper Boquillas-Terlingua unit is a good example of vertical lithologic gradation. Yet sufficient difference permits the recognition of three lithostratigraphic units. The tops of two biostratigraphic zones provide convenient markers in the section and are the basis for the divisions shown in Figure 2.

LOWER CHALKY SHALE MEMBER: The transitional Fizzle Flat lentil might be considered a lithic average of the Boquillas and Terlingua formations; still it has a distinctive character that makes it a recognizable rock unit (Pl. 2, fig. 2). The lentil is yellowish, and its lithic composition is similar to that of the underlying Boquillas flags. Yet laminae, biscuit-shaped nodular weathering, gray color on fresh surfaces, scarcity of fossils, lack of vegetation, and gentle slopes suggest the overlying Terlingua shale. The relatively sharp contact of the Fizzle Flat lentil with the underlying *Austiniceras?* ledge and the several common properties of the lentil and the Terlingua favor the inclusion of the 50-foot lentil as the base of the upper Boquillas-Terlingua unit. The upper contact of the lentil with the overlying gray shale is gradational within a few feet. This contact is clearly exposed just southwest of the Cheosa Waterhole fault scarp on the road leading westward toward Cheosa Waterhole (C) from the Alpine and Terlingua road. Specimens of Stephenson's *Inoceramus* sp. (with straight radiating ribs) were collected from the top of the lentil at this locality.

Approximately 90 feet of gray, relatively unfossiliferous, calcareous shale lies between the Fizzle Flat lentil and the *Inoceramus undulato-plicatus* zone. This shale weathers to biscuit-shaped nodules on steep slopes.

Thin beds of hard, white, chalky limestone appear in the gray shale section some 60 feet above the top of the lentil, and they become more abundant upward toward the *Inoceramus undulato-plicatus* zone. These chalk beds contain few fossils, are nodular, highly jointed, and average 6 inches in thickness. The alternating gray and white beds characterize the 30 feet of section below the *Inoceramus undulato-plicatus* zone.

The *Inoceramus undulato-plicatus* zone was chosen as the top of the lower chalky shale member, because it is everywhere a recognizable lithologic and paleontologic marker. In places the zone attains a thickness of 12 feet. It consists of very fossiliferous, hard, light creamy yellow-gray, unevenly bedded, nodular, silty limestone ledges and silty shale. So consistently do the ledges hold up dip-slopes that the resulting cuestas and hogbacks are easily recognized even on small-scale aerial photographs.

The total thickness of the lower chalky shale member is about 150 feet.

Section of the lower portion of the upper Boquillas-Terlingua unit measured in the Blue Hills area 1 mile south-southwest of Clanton ranch

Thickness *Feet*

Upper Boquillas-Terlingua unit—

10. *Inoceramus undulato-plicatus* zone: Over-all color is light creamy yellow-gray. Basal 1 foot is a hard limestone bed; next is a 1-foot section of irregularly bedded, nodular, silty limestone; then 4 feet of silty shales; and the up-

PLATE 2.—BOQUILLAS-TERLINGUA SEQUENCE

FIGURE 1. LOWER BOQUILLAS-TERLINGUA UNIT

Middle terraced member in foreground, upper shaly member in cliff in background. On Terlingua Creek upstream from mouth of Alamo de Cesario Creek. (Photograph by R. B. Davis.)

FIGURE 2. FIFTY-FOOT FIZZLE FLAT LENTIL, PRACTICALLY BARREN OF VEGETATION

Flat-lying Boquillas flags in Cheosa Waterhole fault scarp in background. Looking eastward toward Nine Point Mesa on horizon. (Photograph by R. B. Davis.)

FIGURE 3. WEST FLANK OF PANTHER MOUNTAIN, A TRAP-DOOR DOME

Lighter-colored Boquillas-Terlingua beds dragged up along darker vertical wall of rhyolitic intrusion. Roof rock on skyline is upper Devils River limestone. (Photograph by R. B. Davis.)

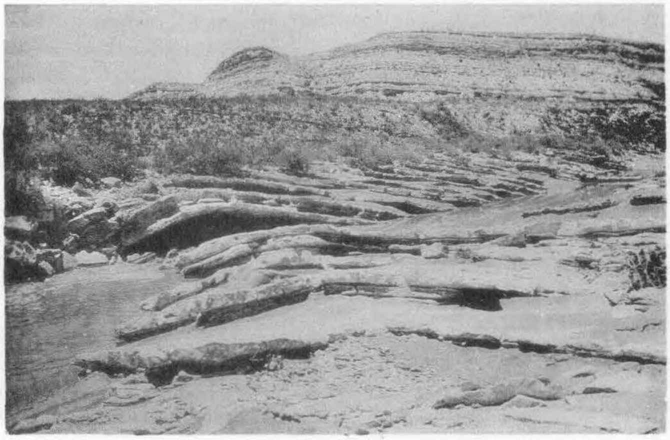

FIGURE 1

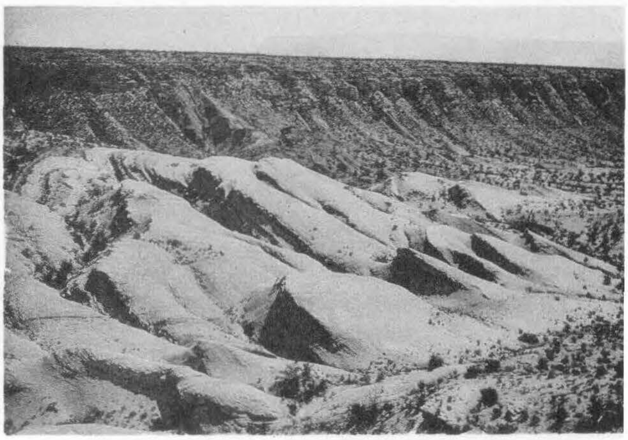

FIGURE 2

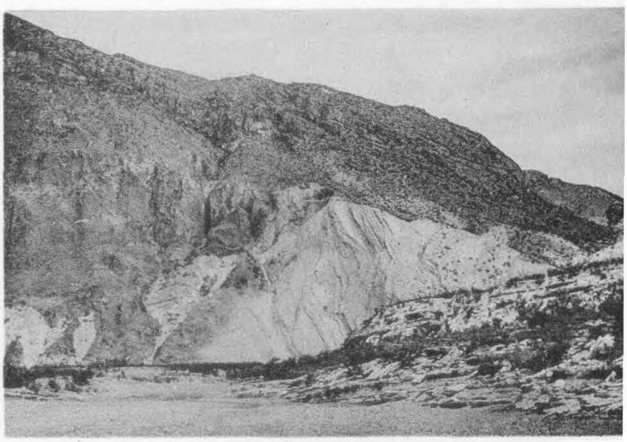

FIGURE 3

BOQUILLAS — TERLINGUA SEQUENCE

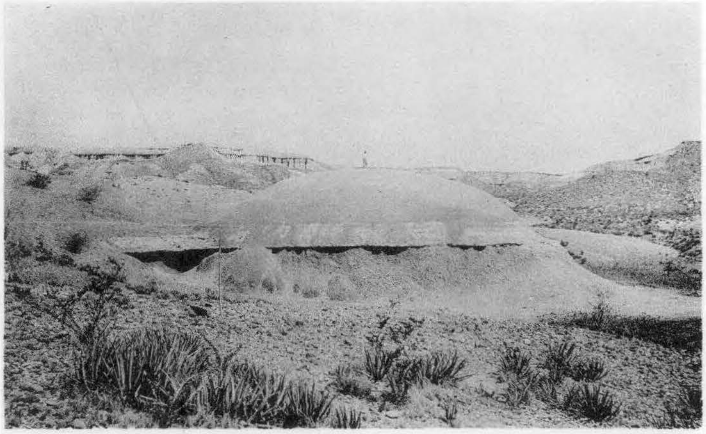

FIGURE 1

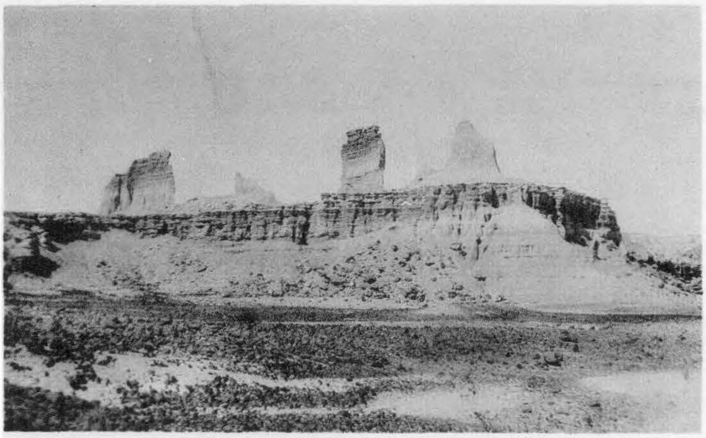

FIGURE 2

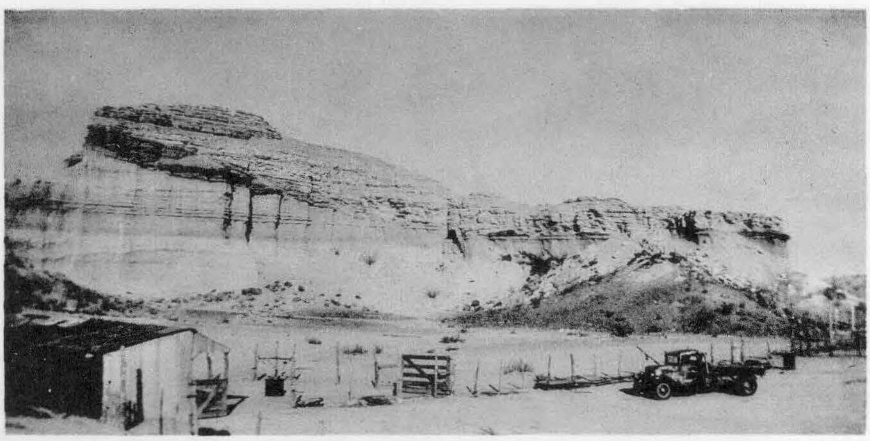

FIGURE 3

TUFFS AND TOPOGRAPHIC FORMS

permost foot is a nodular, impure, silty limestone with numerous *Inoceramus undulato-plicatus* Roemer. These limestone ledges produce dip-slopes characterized by creosote bush vegetation............................ 7

9. Gray shale section: at some horizons calcareous enough and sufficiently indurated to form zones of large, jointed, nodular, fossiliferous, concretionary masses or individual thin beds of shaly, chalky limestone. Interval becomes sandy (fine-grained) and yellowish in uppermost 5 feet..... 27

8. Hard, glaring white limestone bed; weathers to odd-shaped, nodular concretionary masses. Highly complex pattern of closely spaced joints; ledge disintegrates into small angular fragments. Some limonitic stain, especially along joints......................... 1

7. Shale similar to unit 5.............. 6.5

6. Bed of hard to indurated, glaring white, chalky limestone. Very intricately jointed......................... 0.75

5. Indurated to friable, gray, laminated, calcareous shale. Very thin bentonitic seam about 10 feet from top of interval. Uppermost 5 feet somewhat silty and has a slightly yellowish tinge. Almost vertical brown clastic dikes and white calcite dikes. Fresh shales are dark gray to black and practically nonfossiliferous........................ 59

4. Fizzle Flat lentil (= "barren" or "transition" zone): Indurated to friable, gray to creamy yellow, laminated to platy, silty, and chalky shale with occasional seams of bentonite less than one-fourth inch thick. More silty and sandy in lower 10 feet and increasingly chalky upward. Thin chalky plates crackle and crunch when walked upon. Everywhere barren of vegetation and typically cream-yellow (gray in unweathered exposures). Some zones exhibit gray biscuit weathering similar to that of typical Terlingua. Brown clastic dikes common. A peculiar *Inoceramus* (species with well-developed, straight, radiating ribs collected by Stephenson) abundant in uppermost part of section. Similar forms with less well-developed ribs occur throughout the lentil. One hard, yellow-brown, nodular limestone with *Inoceramus* cf. *labiatus* Schlotheim at top................................. 50

Lower Boquillas-Terlingua unit—

3. Hard, light-brownish, thin, and unevenly bedded, somewhat nodular, sandy limestone bed. *Ostrea congesta* Conrad abundant and a few poorly preserved inocerami................... 0.25

2. *Austiniceras?* ledge: Whitish to brownish-gray silty shales and thin, irregularly bedded, nodular, impure silty limestone ledges. Same fossils as unit 1, plus a thin sharp-keeled, cart-wheel ammonite 28 inches in diameter *(Austiniceras?)* and a ribbed *Inoceramus* similar to that at top of Fizzle Flat lentil........................... 4

1. Top of hard, most resistant, yellowish-brown to white, silty limestone ledge, about 1 foot thick, near top (?) of Boquillas. All fossils poorly preserved; *Ostrea congesta* Conrad attached to a large *Inoceramus* with concentric undulations and fine rugae, an ammonite 2 to 3 inches in diameter, *Inoceramus labiatus?* Schlotheim, and part of an ammonite 9 to 10 inches in diameter.

PLATE 3.—TUFFS AND TOPOGRAPHIC FORMS

FIGURE 1. WHALEBACK HILL IN TUFF OF NORTHWESTERN PART OF QUADRANGLE
(Photograph by R. B. Davis)

FIGURE 2. GROTESQUE EFFECTS IN DEVILS GRAVEYARD PRODUCED BY COMBINATIONS OF RESISTANT AND WEAK BEDS IN TUFF

FIGURE 3. UNCONFORMITY WITHIN BUCK HILL VOLCANIC SERIES AT WHISTLER SQUAT

Several dark conglomerate lenses occur just above break separating calcareous tuff below from more calcareous tuff above.

MIDDLE SHALE MEMBER: The 90-foot interval above the *Inoceramus undulato-plicatus* zone consists essentially of loose to friable, gray, laminated calcareous shale that weathers to biscuit-shaped nodules. Portions of the shale section are silty and weather to a dingy cream-gray; *Ostrea* fragments and *Inoceramus* prisms are randomly distributed. Thin seams of light-brown, fine-grained sandstone occur at irregular and widely spaced intervals. Disseminated gypsum and a small percentage of fine-grained sand appear in the shale upward from 50 to 65 feet above the *Inoceramus undulato-plicatus* zone, respectively. Those parts of the section with a sandy content weather to a creamy yellow at most places.

Some thin, brown sandstone beds about 75 feet above the *Inoceramus undulato-plicatus* zone are, more correctly, a sandy agglomerate of *Inoceramus* prisms. This larger sized bioclastic material suggests more turbulent waters during the time the beds were deposited.

A 10- to 15-foot sequence of gray calcareous shale, which includes a few thin beds of hard, pure-white, highly jointed, nodular and concretionary chalky limestone, is present just below the giant *Inoceramus* beds. Large *Texanites* are common in the thin chalky ledges. This lithologic sequence is similar to that just below the *Inoceramus undulato-plicatus* zone.

The giant *Inoceramus* beds, a less obvious stratigraphic marker than the *Inoceramus undulato-plicatus* zone, occur about 100 feet above the latter and are named for an extremely large species of *Inoceramus* that is abundant in them. Most of the fossil remains are internal molds up to 3 feet across, but very thick prisms and massive hinge-line structures are also found. The giant *Inoceramus* section is variable in thickness, but 35 feet is probably an average figure. Lithologically these chalky fossil beds do not everywhere contrast sufficiently with the enclosing gray shale to permit reliable identification. They do not consistently form persistent dip-slopes as do the *Inoceramus undulato-plicatus* zone and the *Austiniceras?* ledge. Where the giant *Inoceramus* beds crop out in a stream valley in which weatherng products are kept scoured off, the limestones are easily recognized as thick white ledges. On hill slopes, the chalky beds are easily covered over and discolored by slope wash so that they blend with the gray shales.

Good outcrops of the prolifically fossiliferous giant *Inoceramus* and *Texanites texanus* beds are found on Terlingua Creek three-quarters of a mile downstream from the mouth of Alamo de Cesario Creek (SC); a mile south of and also a mile east-southeast of Whistler Squat (SW); and 2 miles east-southeast of Clanton ranch (C).

A generalized sequence of the beds just under the giant *Inoceramus* beds 1 mile east-southeast of Whistler Squat is:

6. 1½-feet of creamy yellow-gray, impure nodular limestone with huge inocerami, *Ostrea congesta* Conrad, *Texanites,* etc.
5. 2± inches of purplish *Gryphaea* agglomerate.
4. 2 feet of impure silty clays.
3. Few inches of yellowish gray, thin-bedded, calcareous sands.
2. Yellow to gray clay-shales.
1. 10- to 15-foot sequence of widely spaced, thin, white, jointed, nodular chalky limestone ledges, with *Texanites,* in a gray calcareous shale.

The giant *Inoceramus* beds appear to vary in hardness from place to place, perhaps due to a variation in $CaCO_3$ content. The beds ordinarily occur as indurated to hard, cream-colored, fairly thick and unevenly bedded, highly fossiliferous, nodular, chalky limestone ledges set in gray, calcareous, silty shales. This section of alternating shales and limestones is 35± feet thick, and the topmost ledge especially is prolific with *Texanites texanus* (Roemer) Spath.

The total thickness of the middle shale member is approximately 135 feet.

Partial section of middle? Terlingua beds measured on west flank of north Pitahaya Hill

	Thickness *Feet*
Terlingua beds—	
8. Soft and loose to friable, light-gray, laminated calcareous shale with disseminated gypsum. Ten feet above base of unit is a thin zone from which numerous fragments of a large *Inoceramus* weather to form slope material. Shells of *Ostrea congesta* Conrad attached to	

these *Inoceramus* prisms. Shaly material weathers to creamy yellow where exposed as a hill top...................... 80+

7. Similar to unit 5...................... 1

6. Similar to unit 4 plus some limonitic stains................................. 8.5

S. Hard, light-brown sandstone layer with fragmentary inocerami. Weathers easily because of nodular character and contributes much slope material........... 1.5

4. Loose to friable, light-gray to gray, laminated, calcareous shale. Fragments of *Inoceramus* and *Ostrea?* shells. Occasional thin seam of light-brown, fine-grained sandstone in lower portion of interval with small amount of bentonite 37

3. Indurated, creamy brown, nodular, impure silty and sandy limestone with fragments of large *Inoceramus* shells. ... 1.5

2. Silty gray shale weathers to a dingy cream-gray. *Inoceramus* fragments... .. 4

1. Top of *Inoceramus undulato-plicatus* zone.

Partial middle Terlingua section measured on west bank of Terlingua Creek three-quarters of a mile downstream from mouth of Alamo de Cesario Creek

Thickness *Feet*

Terlingua beds—

3. *Texanites texanus* bed: Indurated to hard, creamy yellow, irregularly bedded and nodular impure marly limestone with giant inocerami.......................... 3.5

2. Friable to indurated, gray, laminated, calcareous silty shale—weathers to biscuit-shaped nodules and yellowish color.. 25

1. Top of resistant, white limestone bed with petroliferous odor and many giant inocerami.

Partial middle? Terlingua section measured on west bank of Terlingua Creek east of Agua Fria Mountain

Thickness *Feet*

Terlingua beds—

3. Indurated, creamy yellow, irregularly bedded, nodular impure limestone and marl with giant inocerami............... 6

2. Loose to friable, gray, laminated calcareous shale........................... 98

1. Top of *Inoceramus undulato-plicalus* zone; somewhat sandy.

UPPER SILTY CLAY MEMBER: The thickness of 200 feet assigned to this member, composed of soft and easily weathered rocks, is an estimate. Gravel-covered slopes, concealed faulting, steep and non-uniform dips, and lack of good bedding made accurate measurement difficult to impossible.

The upper silty clay member grades into the overlying Aguja sandstone. For mapping purposes, the first true sandstone bed was arbitrarily chosen as the base of the Aguja. By definition, then, this member, in the Agua Fria quadrangle, consists of those beds lying between the base of the lowermost hard, rusty brown sandstone bed of the Aguja formation and the top of the *Texanites texanus* bed some 200 feet below.

The basal beds of this member are typical gray Terlingua shale. A gradation upward results in a rusty brown silty marl. Gypsum, already noted in the middle member, steadily increases in percentage from bottom to top so that large plates, which glitter in the sunlight, occur in the higher beds.

Silty clay-shale occurs 50 to 60 feet above the middle member, and the section becomes still more silty upward. Originally grayish, the clay-shale weathers to a dirty yellow.

Slightly sandy, yellowish, friable to loose clay and shale with numerous *Gryphaea wratheri* Stephenson and very thick prisms and hinge-line structures of a large *Inoceramus* occur fairly high in the upper member.

The thickness of the youngest Terlingua section or transitional beds varies with locality because of gradation. In places the Terlingua is loose, light-brown, massively bedded, bentonitic, fine-grained sandy or silty clay with a carpet walk: The swelling of the bentonitic clays produces a cushiony effect, which makes one feel that he is walking on a plush carpet.

The transitional beds are highly gypsiferous, and large plates of clear gypsum sparkle like jewels on some hillsides. A white, crusty efflorescence appears in many places on the surfaces of this dull yellow-gray silty clay. Many large, isolated *Inoceramus* shells are found in the transitional beds. Large white calcareous concretions and septaria, many of which appear to be cracked chalky limestone nodules, are outstanding features; most are scattered throughout the sandy clay section, but some occur in definite horizons.

The upper silty clay member of the upper Boquillas-Terlingua unit is exposed northeast of Agua Fria Mountain, north of north Pitahaya Hill (SE), and half a mile east of Mesquite Tank (SW). An estimated 200 feet of the gray marly shale and clay lies above the *Texanites texanas* beds east of Agua Fria Mountain, and the gradation into the overlying Aguja is visible. The best exposure of an almost complete upper section lies half a mile east of Mesquite Tank, but the locality is rather inaccessible, and the slopes are almost vertical; so a detailed measurement is practically impossible. Approximately 200 feet of faintly greenish yellow-brown silty clay, overlain by 20 to 40 feet of undisputed Aguja sandstone, with a wavy unconformity at its top, plus 15 to 20 feet of basal Tertiary conglomerate are excellently exposed. A good and easily accessible locality of the Terlingua-Aguja transition zone is 1 mile northeast of Clanton ranch.

Section of upper Terlingua beds beginning at top of Inoceramus undulato-plicatus zone southeast of Hill 3494 (SC) and working northeastward toward inlier of Aguja

	Thickness *Feet*
Aguja? sandstone—	
9. Hard, rusty brown bed of fine-grained sandstone	1
Terlingua beds—	
8. Transition zone with carpet walk. Loose, light-brown, massively bedded, highly gypsiferous, bentonitic, fine-grained sandy or silty clay. White calcareous septaria	52
7. Typical gray shales in basal 50 feet. White calcareous concretions appear 55 feet above base of unit. Section weathers yellowish upward. Large plates of gypsum in upper 50 feet. Base of 20-foot zone of scattered, white, jointed, chalky concretions occurs 50 feet below top of unit. Thirty feet below top, thin beds of fine-grained, yellowish-brown to light brown sandstone appear. Just above lowermost thin sandstone bed is a 2-inch bed of white, highly jointed, chalky limestone	130?
6. Covered and thickness questionable (measured on basis of projected dip)	15?
5. Top of *Texanites texanus* bed.	
(Section broken by faulting)	
4. Giant *Inoceramus* beds: At base is a 1-foot, cream-colored, nodular, chalky ledge; then 5 feet of silty shale; next a resistant, prominent, 1-foot thick nodular limestone ledge; 5 feet more of shale; and at the top another 1-foot, nodular, chalky ledge. (Probably an incomplete section of these beds.)	13
3. Friable to loose, dark-gray to black, finely laminated calcareous shale cut by brown clastic dikes; gypsum present but not abundant. Slopes weather to a soft, loose, gray material, are littered with *Inoceramus* prisms, *Ostrea* fragments, and small pieces of brown, thin-bedded sandstone and sandy agglomerate of individual *Inoceramus* prisms. Fine-grained sand content appears about 30 feet above base of unit and color of section upward is creamy yellow (probably due mostly to weathering). A more calcareous and better indurated 1-foot bed of shale stands out on face of cliff 38 feet above base	72
2. Covered	35
1. Top of *Inoceramus undulato-plicatus* zone.	

A striking characteristic of the upper Boquillas-Terlingua unit is its soft gray color, but local shades of light brown and yellow result from weathering. This is exemplified by the yellowish-brown tops of the gray cliffs along Terlingua Creek where the gray-brown color contact crosses bedding planes of the dipping strata.

There is believed to be but one *Inoceramus undulato-plicatus* zone in the Agua Fria quadrangle, as revealed by outcrops along the 2-mile stretch of Terlingua Creek just west of Clanton ranch and at other localities, but the zone has been repeated by faulting in the section exposed along Cat Draw (C and WC) and at several other places.

Thin, persistent, almost vertical clastic dikes of fine-grained brown sandstone—and also white calcite dikes—are common, especially in the lower part of the unit. An impression of an *Inoceramus* was found in one of the clastic dikes in the Blue Hills area 1 mile south-southwest of Clanton ranch.

FOSSILS: The paleontology of the upper Boquillas-Terlingua unit is summarized, tentatively, as follows (thicknesses in feet shown in parentheses):

Upper silty clay member (200?)—
- "Transitional beds" (50?)—
  - *Inoceramus* sp.
- Silty clay (150?)—
  - *Gryphaea wratheri* Stephenson
  - *Gryphaea aucella?* Roemer
  - *Inoceramus* sp. (large, with thick prisms)
  - *Ostrea congesta* Conrad
  - Thin pelecypod? shell fragment with numerous short spines *(Spondylus?)*

Middle shale member (135)—
- *Texanites texanus* bed and giant *Inoceramus* beds (35±)—
  - *Hemiaster texanus* Roemer
  - A brachiopod
  - *Inoceramus* sp. (giant, up to 3 feet across)
  - *Inoceramus* sp.
  - *Gryphaea wratheri* Stephenson
  - *Gryphaea* sp.
  - *Ostrea congesta* Conrad
  - *Ostrea* sp.
  - *Spondylus guadalupae?* Roemer
  - *Durania terlinguae* Adkins
  - Pelecypod? shell fragment with small spines
  - *Eutrephoceras* sp.
  - *Texanites texanus* (Roemer) Spath
  - *Texanites* sp. (thin)
  - *Placenticeras* sp.
  - *Parapachydiscus?*
  - *"Hamites"*
  - Other unidentified ammonites
  - Small cephalopod? with a rostrate venter
  - *Onychodus?* teeth
- White chalky ledges (15±)—
  - *Texanites texanus* (Roemer) Spath
- Gray shale (85)—
  - *Inoceramus* sp. (large shells, thick prisms)
  - *Ostrea* sp.

Lower chalky shale member (150)—
- *Inoceramus undulato-plicatus* zone (10±)—
  - *Inoceramus undulato-plicatus* Roemer
  - *Inoceramus* sp. (thin shell)
  - *Gryphaea wratheri* Stephenson
  - *Texanites* cf. *texanus* (Roemer) Spath
  - *Texanites* sp. (thin)
  - *Peroniceras?* (or an evolute *Texanites)*
  - *Gauthiericeras?* (or *Texanites?)*
  - *Texanites?* (18 inches in diameter, 3¾ inches thick)
  - *Texanites?* (1+ foot across; 5 prominent nodes on each rib)
  - *Placenticeras?*
  - *Onychodus?* teeth
- White chalky ledges (30)—
  - *Inoceramus* cf. *subquadratus* Schlüter
  - *Inoceramus* sp.
  - *Anisomyon patelliformis* Meek and Hayden
  - *Texanites* sp.
- Gray shale (60)—
  - *Inoceramus* sp.
- Fizzle Flat lentil (50)—
  - *Inoceramus* sp. (with straight ribs)
  - *Inoceramus* sp. (with strong undulations)
  - *Inoceramus* cf. *labiatus* Schlotheim
  - *Ostrea* sp.
  - *Prionotropis?* (small)
  - Other small ammonites
  - Isopods??
  - Shark teeth
  - Bone fragment

Stephenson (1948) said of the *Inoceramus* sp. (with straight ribs):

> "In the upper part of the transition zone [Fizzle Flat lentil] is a distinctive species of *Inoceramus* (with radiating costae), the significance of which as an index fossil has not yet been determined. This appears to be the species that Adkins compared to *Inoceramus digitatus* Sowerby, and he considered it to be an Austin species."

On the basis of this statement, the writer is inclined to call the Fizzle Flat lentil, provisionally, basal Terlingua, although certain species of *Inoceramus* and ammonites found in the lentil strongly suggest similar forms found lower in the Boquillas section. Perhaps a more thorough paleontological study of the lentil will reveal an intermingling of both Austin and Eagle Ford forms within it. The Fizzle

Flat lentil in the Agua Fria quadrangle is a distinct lithologic unit that could serve as a key unit to which later-discovered paleontologic zones can be referred.

STRATIGRAPHIC RELATIONS: Both upper and lower contacts of Udden's Terlingua formation are gradational, and the transition upward into the Aguja is very gradual. Ross A. Maxwell, working in the Big Bend National Park, finds many *Exogyra ponderosa* Roemer about 100 feet below the top of his Terlingua formation. F. L. Whitney (personal communication) stated: "*Exogyra ponderosa* Roemer occurs on Little Walnut Creek near Sprinkle a few miles from Austin, probably 15 to 20 feet below *Exogyra tigrina* and *Exogyra laeviuscula* and, therefore, quite a distance below the Austin-Taylor contact." *Exogyra ponderosa* has not been found in the Agua Fria area. Because this fossil is found below the Austin-Taylor contact in central Texas, its absence here suggests the possibility that the uppermost Terlingua beds in this area are Austin in age and that none of them are young enough to be called Taylor.

Aguja formation.—Adkins (1933, p. 505, 506) wrote:

"When in 1907 Dr. Udden described his 'Rattlesnake' formation, the name had already been used for a formation in the Oregon Pliocene. Accordingly the name Aguja is here substituted for Udden's name. The type locality is Sierra Aguja (Needle Peak), in the flat in front of the Santa Helena fault scarp, 6 miles south of Terlingua, Brewster County, Texas. The slopes and surrounding flats contain a practically complete section of the beds, overlain by the Tornillo clay, and situated close to Udden's original type locality. . . .Three widespread types of sediments compose the Aguja: (1) rather coarse grained fossiliferous sandstones, weathering to dark brown, tan, yellowish-brown, and blue-gray shades; (2) lustrous to dull black, non-marine, carbonaceous, lignite-bearing shales . . . ; (3) massive shelly clays, somewhat like those in the Taylor but generally weathering more yellowish-brown, and generally more sandy or silty."

The lower part of the Aguja is of Taylor age, and Adkins assigned the upper part to the Navarro. The Aguja is the youngest Cretaceous formation in the Agua Fria area.

OUTCROP: The easily eroded Aguja generally crops out in the Agua Fria quadrangle only where conditions for preservation are favorable—down-dropped fault blocks and places where the soft Aguja is protected by an igneous cap, the basal Tertiary conglomerate, talus, or a gravel cover.

Isolated Aguja outcrops are found southwest, west, and north of Agua Fria Mountain; south of Half Dome; south of the Fizzle Flat fault scarp; a mile east of Clanton ranch; Pitahaya Hills; and the extreme southeast corner of the quadrangle. All these exposures except the one near Clanton ranch are confined to the southern third of the area.

THICKNESS AND LITHOLOGY: The occurrence of the Aguja in relatively small isolated patches plus a major unconformity that affects principally the Terlingua and Aguja formations eliminate the possibility of a complete Aguja section in the Agua Fria quadrangle.

The outcrops of Aguja immediately south of Half Dome consist primarily of sandstone and shale. The shale is light to dark gray or almost black and blackish-red. Lignite is present, and lignitic shales are fairly abundant. One light-gray sandstone bed is so loosely cemented that it weathers to piles of sand that have been shaped into dune-like forms by the wind. This sandstone bed contains many fossils, oysters and shark teeth the most abundant. Also typical are calcareous concretions, ironstone concretions and septaria with aragonite fillings, fucoids, and cone-in-cone structures. Common minerals are gypsum and barite. The over-all color of these exposures is rusty brown. The Aguja fault blocks are synclinal with steep dips, so that much section can be seen in a short horizontal distance.

The most accessible Aguja occurs in a fault block east of the Clanton ranch, where the formation is exposed for an east-west distance of almost 2 miles. The Terlingua-Aguja transitional zone, in which the gray silty to sandy clay of the Terlingua grades upward into yellowish-gray, gray, and brown Aguja sandstone, is well exposed 1 mile northeast of the ranch house. The Aguja consists mostly of brownish sandstone and sandy clay of such heterogeneous character that the weathered outcrop resembles a mine dump. Both high-and low-spired gastropods and oyster shell fragments were found north of the road 2 miles east of the ranch, and practically all the sedimentary structures of the area south of Half Dome were found at the Clanton ranch locality.

The lower Aguja sandstone in the extreme southeast corner of the quadrangle is so well cemented with calcareous and ferruginous cements that it holds up a prominent north-northwest trending fault scarp. About halfway up the scarp face is a prolific fossil zone. At another near-by locality of a stratigraphically higher position, numerous oysters weather from a ferruginous sandstone. These can be found on the dip-slope inclined eastwardly toward Hill 4142 at the intersection of the fence line and a north-south draw. South of Hill 4142, possibly in the middle Aguja beds, large fragments of dinosaur bones and armor plates, ironstone beds and concretions, cone-in-cone structures, calcareous septaria, ripple marks, and much gypsum were found in the yellowish-brown sandy clay, thin-bedded and laminated sandstone, and massive beds of friable, light-yellow sand. No lignitic shale was observed in this area, which is indirect evidence for assigning these outcrops to the lower Aguja.

The uppermost Terlingua, the Terlingua-Aguja transition zone, and the basal Aguja are exposed on the north slopes of north Pitahaya Hill. This combined section is buff or yellowish-brown, poorly consolidated, gypsum is abundant, and numerous calcareous septaria occur just below the igneous cap. Massively bedded silty clay or marl, which grades from yellowish brown-gray at base to rusty yellowish-brown at top, makes up almost the entire section at the south end of the same hill. Slope materials are loose to friable due to the bentonite, sand, and silt content, and a cushiony or carpet walk results. Many large slabs of clear gypsum are present near the base of the hill. Higher in the section thin beds of yellow, laminated to platy fine-grained sandstone, calcareous septaria with brown calcite and aragonite vein fillings, and cone-in-cone structures appear. There is an occasional massive bed of loose to friable light-yellow sand, and few layers of rusty brown sandstone occur in the massive clays near the top of the hill. One small gastropod was found about halfway up the hill.

Northwest of Packsaddle Mountain, the normal gray Terlingua clay grades upward into low, whaleback-shaped hills of brownish Aguja. Walking or driving an automobile on the flat just north of these hills is difficult, for it is underlain by the soft, bentonitic cushiony Terlingua-Aguja transition zone. Where exposures are best, the upper gray Terlingua grades into light-brown Terlingua-Aguja and this into brown basal Aguja, from which fragments of hematite weather.

The Aguja is exposed over a large area north of Agua Fria Mountain. The Terlingua-Aguja contact extending from Agua Fria Mountain to Paint Mountain can be located fairly closely on aerial photographs because of the different topographic patterns that develop in the two formations. Although too small to be shown on the map, several outcrops of disturbed Aguja beds occur along the Tascotal Mesa fault west of Paint Mountain.

Lignitic shale of the Aguja crops out at Agua Fria Spring. These beds are part of a very narrow Aguja fault block which fringes Agua Fria Mountain to the northwest, west, and southwest. Undoubtedly the high permeability of the lower Aguja sandstone partially accounts for the perennial spring.

Aguja fragments and sedimentary structures in the dams of earthen stock tanks indicate that much of the alluvium-covered flat between south Pitahaya Hill and Camels Hump is underlain by Aguja. Aguja beds concealed by a thin alluvium sheet are probably continuous from south Pitahaya Hill to the southeast corner of the quadrangle.

In most places, the lower Aguja section consists of loosely cemented, light-colored sandstone. Although rare in the Agua Fria area, cannonball concretions are abundant in the lower sandstones farther south.

Partial section of lower Aguja measured on west side of hill 1-3/4 miles southwest of Clanton ranch

Aguja sandstone—

12. Top of hill.

11. Friable to indurated, yellowish-gray to dark-gray, fine-grained sandstone.

	Thickness feet.
Bedding consists of poorly developed irregular plates within a massive bed. A few poorly preserved ripple marks............................	3.5
10. Loose, whitish-gray, massively bedded, fine-grained sand..............	10
9. Loose to friable, brownish-gray, massively bedded, somewhat bentonitic silty clays and marls with occasional small white limy concretions and few very thin rusty brown sandstone layers............	27
8. Hard to indurated, light-brown, fine-grained sandstone. Weathers to plates. Ripple mark impressions preserved in base.....................	2
7. Large, hard, yellowish- to light-brown, flattened, somewhat connected, lenticular limestone concretions enclosed in fine-grained sandstone matrix....................	0.5 to 1
6. Thin bed of indurated, tan to light rusty brown, fine-grained sandstone. Breaks down to fragments of pebble and cobble size...................	0.5
5. Loose, dull olive-green to light-brown, massively bedded, silty clay-shale with 6-inch parting of rusty brown sandstone 15 feet above base. White chalky concretions scattered throughout bentonitic section. Large gypsum plates as float on slopes....................	42
4. Hard, rusty brown bed of highly fractured fine-grained sandstone with broad, symmetrical ripple marks (3 inches from crest to crest). .	0.5
3. Loose, rusty brown, massively bedded, gypsiferous and bentonitic silty clay..........................	14
2. Hard, rusty brown bed of fine-grained sandstone (= lowest good sandstone).........................	1
Total lower Aguja present	101.5
Terlingua? beds—	
1. Transitional zone: Loose, light-brown, massively bedded, highly gypsiferous, bentonitic, fine-grained sandy to silty clay with carpet walk. White calcareous septaria....	52

At two small outcrops of Aguja, sandstone has been altered to quartzite by contact metamorphism. One locality is Hill 3473 (SE), and the other is on the downthrown side of Cheosa Waterhole fault just west of its intersection with latitude 29°35′ N. The latter is a small outlier where an uncovered decomposed sill (?), which exhibits excellent spheroidal weathering, is preserved in the depression of a saucer-shaped structural basin. The Aguja beds within 10 feet below the igneous contact have been metamorphosed to a dark rusty reddish-brown quartzite, which forms the rim of the saucer. Pelecypods are not obliterated in the quartzites, and ordinary indurated to friable Aguja sandstone with cone-in-cone structures, petrified wood, and gypsum is present below the metamorphosed section.

FOSSILS: The only *original* organic remains collected from the Aguja are oyster shells, fish teeth, and fragments of reptilian bones, armor plates, and turtle shells. All other fossils consist of internal and external molds, the identification of which is indefinite. A tentative list of fossils collected from several localities follows:

North end of south Pitahaya Hill—
- *Ostrea* sp. (large, elongate)
- *Volutomorpha?*

Two miles east of Clanton ranch—
- *Ostrea* sp.
- *Corbula?*
- *Inoceramus?*
- Small indeterminate ribbed pelecypod
- *Natica?*
- *Volutomorpha?*

Halfway up south end of north Pitahaya Hill—
- *Volutomorpha?*

South of Half Dome—
- *Ostrea* spp.
- Fucoids
- Teeth of *Lamna texana*

South of Hill 4142 (SE)—
- Fragments of dinosaur bones
- Fragments of dinosaur armor plates

Prolific fossil bed halfway up fault scarp half a mile west of Hill 4142 (SE)—
- *Ostrea* sp.
- Numerous internal molds of a medium-sized pelecypod
- *Cardium?*
- *Turritetta trilira* Conrad
- *Natica* sp.
- *Volutomorpha?* spp.
- *Calliomphalus?*
- Other impressions and molds of gastropods
- *Baculites* sp.
- *Lamna texana* tooth

STRATIGRAPHIC RELATIONS: The contact of the Aguja with the underlying Terlingua is gradational. Wherever the Aguja is overlain by Tertiary rocks, the contact is distinctly marked by an unconformity which is angular in some localities and apparently disconformable in others.

In his unpublished "Notes on the stratigraphy of the Upper Cretaceous formations of the Big Bend area, Texas," Stephenson (1948) stated: "I was not able to find any fossils in the upper Aguja that suggest an age as young as Navarro." Although composed of poor specimens, the suite of fossils collected from the Aguja in the Agua Fria area indicates Taylor age. The writer is of the opinion that no Cretaceous beds in the Agua Fria quadrangle are younger than Taylor.

Tertiary

General description.—The Tertiary rocks of the Agua Fria area consist of a volcanic series, principally calcareous tuff. Conglomerate, sandstone, breccia, fresh-water limestone, and intercalated lava flows occur in subordinate amounts. Nonmarine fossils collected from calcareous tuff and limestone beds indicate that some of the stratified section was deposited in fresh-water lakes. Change in thickness of beds and in lateral and vertical facies characterizes the tuff section (Pl. 3, fig. 3).

Buck Hill volcanic series.—The name Buck Hill volcanic series was applied by Goldich and Elms (1949, p. 1143–1163) to the Tertiary volcanic succession, 3000–4000 feet thick, that lies unconformably on Cretaceous strata in the area between the Alpine intrusive igneous center on the north and the Terlingua center to the south, and which extends into the Agua Fria quadrangle. Goldich and Seward (1948, p. 10-36) and Goldich and Elms (1949) divide the Buck Hill volcanic series into three formations:

Tascotal formation...............	1000 ± feet
Duff formation..................	1000–1400 feet
Pruett formation................	900–1000 feet

The Pruett formation consists chiefly of well-indurated, thick to thin-bedded, commonly calcareous tuff that is normally grayish-white to bluish-gray or may be variegated and banded in many colors. The tuff section includes conglomerate, tuffaceous sandstone and breccia, tuffaceous fresh-water limestone, and interfingering lava flows. The base of the Pruett generally is marked by a limestone pebble conglomerate and conglomeratic arkosic sandstone. Goldich and Elms assign the Pruett formation, in part at least, to the Eocene.

The Duff formation is composed primarily of well-lithified, grayish-white but commonly variegated, massive to thin-bedded, rhyolitic tuff with subordinate amounts of sandstone, breccia, and conglomerate. The Duff tuff is essentially noncalcareous, and no fresh-water limestone has been found. The formation is probably Oligocene in age.

The lower part of the Tascotal formation consists of glaring white, thin-bedded, flaggy, sandy tuff. The upper part includes gray-buff, cross-bedded, coarse-grained, tuffaceous sand with minor amounts of breccia and conglomerate. The age is Oligocene (?) or younger.

Goldich and Elms (1949, p. 1145) correlated the Buck Hill volcanic series, in part, with the 2000 feet of tuffaceous sediments in the Chisos Mountains described by Udden (1907b, p. 60–66) as the Chisos beds and with the 3500-foot thick Squaw Peak volcanic series in the Quitman Mountains described by Huffington (1943, p. 1027–1046). Huffington assigned this volcanic section to the lower Tertiary, Eocene or Oligocene.

In the Agua Fria quadrangle, only the lower part of the Buck Hill volcanic series is present. Most of the rocks are Pruett with possibly a partial section of Duff. The sequence is referred to only as the Buck Hill volcanic series and is not divided. In the Buck Hill quadrangle, formation boundaries were established on lava flows and lithologic characters not present in the Agua Fria quadrangle. In addition, exposures are inadequate to permit tracing of individual beds or zones into the quadrangle or to make possible the measurement of a composite section.

OUTCROP: The Buck Hill volcanic series, at most places capped by Quaternary gravel, is confined almost entirely to a north-south strip, which lies between longitudes 103°40′ and 103°45′ W. Owing to gentle westerly regional dip of the Tertiary tuff, progressively younger strata are encountered to the west. Outliers of the basal Tertiary conglomerate are not uncommon in other parts of the quadrangle; but, as a general rule, very few are found northeast of a line connecting Camels Hump (SE) with Hale Cabin (NC).

Because the tuffs erode relatively easily, sections of greatest thickness are preserved where tuff is protected by a gravel cover or an igneous cap. The tuffs formerly extended farther east and probably covered the entire quadrangle, but erosion has almost stripped them from the eastern two-thirds of the area.

THICKNESS: Goldich and Seward (1948, p. 15) state that "the cumulative thickness of the Tertiary volcanic succession is well over 3000 feet." The Buck Hill volcanic series is not this thick in the Agua Fria quadrangle, but 1000 feet is considered a fairly reasonable estimate.

BASAL TERTIARY CONGLOMERATE: The basal Tertiary or basal Pruett conglomerate is the most persistent member of the volcanic section in the Agua Fria quadrangle; an angular unconformity separates it from the underlying Cretaceous strata. The conglomerate, in its most abundant type, consists of well-rounded pebbles and cobbles of hard, gray Comanche limestones. The fragments, some of which contain siliceous oolites and silicified fossils, are tightly cemented in a gray to brown, coarse-grained, sandy matrix. More angular pebbles of brown and black chert are less abundant, and Gulf Cretaceous materials are present locally. This type of conglomerate is common in the northwest part of the quadrangle.

No igneous pebbles were observed in the basal Pruett conglomerate. This suggests that the igneous centers either were non-existent or had not yet been uncovered at the time the basal conglomerate was deposited. Conglomerates and breccias higher in the tuff series contain notable percentages of igneous fragments.

Remnants of the basal Tertiary conglomerate are widespread, and presumably it once covered the entire quadrangle. Loose, rounded pebbles and cobbles are abundant in spots in the southeast corner of the area. *Orbitolina texana* Roemer, which indicates a Glen Rose source, is abundant in some of the rounded fragments. On the northeast flank of Hill 4142, a bench or terrace in the Aguja is held up by a tightly cemented cap of the conglomerate.

An unusual development of the conglomerate occurs on the west flank of Hill 4207 (SW) and extends westward into the Tascotal Mesa quadrangle. Most of the pebbles, cobbles, and boulders (some more than a foot in diameter) are fragments of a very hard, coarsely crystalline, white or gray to light-brown limestone that contains gray to brown flint nodules and silicified colonial corals, branching corals, rudistids, and *Cerithium.* The siliceous material stands out in relief, and the faunal assemblage suggests the Edwards equivalent of the Devils River as a source. The conglomerate also contains chert and flint pebbles. At Hill 4207, the few feet of conglomerate rests on the Boquillas flags; but within a half mile to the west, due to the strong east dip of the Comanche section, remnants of the tightly cemented conglomerate cap the Buda limestone, then the Grayson marl (on which the conglomerate slumps), and still farther west the conglomerate rests on uppermost Devils River limestone. Because the conglomerate dips to the east at a gentler rate than the Cretaceous strata, the Cretaceous-Tertiary unconformity is markedly angular in this area.

Some modification from the typical basal Pruett conglomerate occurs in the central part of the quadrangle. In the small hill half a mile northwest of Cheosa Waterhole (C), about 15 feet of the conglomerate caps Terlingua beds. The lower 5 feet consists of the regular rounded limestone pebbles and cobbles plus angular boulders of Aguja sandstone, 1 to 3 feet in maximum dimension, tightly cemented in a sandstone matrix. About 5 feet of the typical conglomerate lies above the Aguja boulders, the angularity of which indicates little transport and a local source. The uppermost 5 feet is a coarse, cross-bedded sandstone with thin conglomeratic layers. Possibly an old land surface on which there were residual Aguja boulders subsided, and then torrential streams deposited the typical basal Pruett conglomerate.

The prominent cuesta 1 mile southwest of B.M. 3540 (C) is capped by the resistant basal Tertiary section. The lowermost beds are coarse-grained sandstone, which, like the underlying Terlingua beds, is highly gypsiferous. Most of the pebbles and cobbles in the conglomerate above the basal sandstone are well-rounded, dark-gray limestones that contain *Orbitolina texana* Roemer, chert, and silicified fossils. These indicate Glen Rose and Devils River sources. Minor amounts of black, brown, and banded chert, petrified wood, and limestone pebbles with small siliceous concretions also are present.

The basal Tertiary conglomerate caps Terlingua in the hills 1½-2 miles northeast of Whistler Squat (SW). The grayish conglomerate is about 2 to 3 feet thick and is composed largely of locally derived Terlingua materials, such as white chalky limestone fragments up to 3± inches in greatest dimension, fragments of *Inoceramus,* and almost complete specimens of *Durania. A* few pebbles of light- to dark-brown banded chert are present. Several feet of gray to light rusty brown, thin-bedded and platy sandstone-breccia lie above the conglomerate.

On the upthrown side and near the northwest extremity of the Fizzle Flat fault, the basal Tertiary is represented by 2 to 3 feet of indurated, rusty gray to reddish-brown, thin-bedded to platy, coarse-grained sandstone. The basal few inches are a sandstone-breccia-conglomerate with limestone pebbles, up to pecan size, probably derived locally from the underlying limestone beds in the Terlingua formation.

The lowermost Tertiary beds are exposed rather extensively about half a mile northwest of Agua Fria Mountain. Fairly typical basal Pruett conglomerate rests on Aguja, and the two are separated by a gently waving unconformity clearly marked by a 2 to 3-inch bed of gypsiferous, limonitic material that contains yellow ochre. A thick section of coarse, gray, cross-bedded sandstone with some breccia rests on the conglomerate. The numerous holes and small caves that weather into this sandstone provide shelter for small animals and give the cliff face an eerie appearance. The conglomeratic section averages 10 feet thick and consists of lenses of conglomerate ranging from a few inches to 2 feet thick. The average pebble size is 1 inch, and the percentage of dark-gray to black chert associated with the dark-gray Comanche limestone pebbles is relatively high. *Inoceramus* prisms are present in the conglomerate, and at some places lenses of creamy yellow, coarse-grained, cross-bedded sandstone are separated by thin seams of impure sandy clay.

Isolated outcrops of the basal Pruett conglomerate immediately north of the Tascotal Mesa fault in the southwest part of the quadrangle cap uppermost Terlingua, the Terlingua-Aguja transition zone, or basal Aguja. The conglomerate reaches a thickness of about 25 feet in the westernmost of these outcrops. The patch of conglomerate 1¼ miles due south of Whistler Squat yields many fragments of petrified wood. The conglomerate is underlain by about 5 feet of friable, yellow-gray, irregularly bedded, coarse-grained sandstone, the lower 1 foot of which is locally a coquina of reworked Cretaceous fossils. The thickness of the conglomerate about a mile southeast of Whistler Squat averages 10 feet, but in places it reaches 20 feet. Very coarse quartzitic sandstone is present as lenses and cementing material in the typical conglomerate. A number of the cobbles are large fragments of poorly rounded Gulf Cretaceous limestone that contains abundant *Inoceramus* shells up to 5 inches in diameter.

The thickest basal Tertiary conglomerate observed occurs in the southwest part of the quadrangle slightly more than a mile northeast of the Solitario fault. Proximity to the Solitario probably accounts for this excessive thickness. The 40- to 50-foot conglomerate section is exposed in an upthrown block at the intersection of two faults 2 miles south-southwest of Whistler Squat. On the fault scarp that faces southwest, typical conglomerate and associated sandstone lenses, reworked Cretaceous materials, and scattered petrified tree trunks appear. The conglomerate is so tightly cemented that pebbles, cobbles, and sandy cementing material fracture alike. Thus relatively smooth, clean breaks result from faulting.

At a point on the north bank of Alamo de Cesario Creek 1-3/4 miles east of Whistler Squat, the gray Terlingua clay-shales are capped unconformably by basal Tertiary gray-brown, cross-bedded, coarse-grained sandstone with some breccia. The wavy unconformity is marked by a brownish, calcareous, gypsiferous, limonitic secondary material.

In a relatively small, almost circular structural basin about half a mile west of Hill 3494 (SC), the following section is preserved.

5. Tuff.
4. Sandstones and sandy clay............50–60 feet
3. Basal Tertiary conglomerate........... 10–12 feet
Unconformity
2. Upper Terlingua...........................50 feet
1. Giant *Inoceramus* beds.

The basal conglomerate is typical except that most pebbles are relatively small—less than 3 inches in diameter. The sandstone and sandy clay section above the conglomerate is rusty brown. The coarser materials of unit 4 are poorly sorted; they range from fine-grained sandstone to sandstone-breccia, and some are cross-bedded. The clayey portion of unit 4 consists of yellow-gray silty clay-shale with nodules and veins of rusty gypsum in cracks and joints. A white efflorescence spottily crusts the surface of the sandy clay. This section resembles some of the Gulf Cretaceous beds, particularly the Aguja; and it suggests a partial derivation of the sandy clay from the weathering and reworking of Aguja and upper Terlingua beds. This sequence is essentially the same as that along the Agua Fria ranch road northwest of Agua Fria Mountain.

The derivation of conglomeratic materials from both local and distant sources is illustrated by the basal Tertiary conglomerate exposed in the bed of Terlingua Creek due east of Paint Mountain. Petrified tree trunks up to 15 inches in diameter and 2+ feet long, ironstone concretions and boulders up to 1.5 feet in diameter, septaria, and fragments of impure limestone that contain cone-in-cone structures presumably were derived locally from the underlying Aguja. Minor quantities of pebbles and cobbles of chert, jasper, and chalcedony indicate a more distant source, for these materials are not characteristic of the Aguja.

In Hill 3494 (SC), about 10 feet of Aguja is preserved under the Cretaceous-Tertiary unconformity, which is marked by secondary rusty brown gypsum. A thin atypical basal conglomerate, nowhere over a few feet thick, was observed. Rusty brown, angular Aguja fragments with minor amounts of limy nodules and concretions are incorporated in a sandy matrix. Thick beds of brownish-gray, coarse-grained, cross-bedded sandstone-breccia lie above the unusual basal conglomerate and substitute for it where it is absent. These lower Tertiary sandstone-breccias include many fragments of petrified wood, and the sequence continues up to the base of the flows (?) that cap the hill.

Reworked *Gryphaea* and *Inoceramus* prisms occur in the basal brownish-gray, coarse-grained sandstone portion of the conglomerate section on Cat Draw (C and WC). Angular fragments of black chert, of coarse-grained sand to pebble size, are present in both the basal sandstone beds and the sandy matrix of the overlying typical conglomerates. This section rests unconformably on the upper Terlingua.

The basal Tertiary conglomerate everywhere rests unconformably on Cretaceous strata, and it is in contact with every Cretaceous formation exposed in the Agua Fria quadrangle. Thus, from a regional viewpoint, the Cretaceous-Tertiary unconformity is angular; but there are local areas in which the discrepancy in dip of the two systems is so slight that the break is more appropriately termed a disconformity.

A diagrammatic north-south cross section drawn from the south part of the Buck Hill quadrangle through the Agua Fria quadrangle would show the following regional relationships between Cretaceous and Tertiary beds. In the Buck Hill quadrangle at Stop 3, Goldich and Seward (1948, p. 27) report the basal Tertiary as largely sandstone with little conglomerate that lies unconformably on the Boquillas limestone. A thickness of 2–4 feet is listed for the conglomerate-sandstone here. Farther to the south, in the north-central part of the Agua Fria quadrangle, the typical conglomerate thickens to 10–15 feet and rests unconformably on the Fizzle Flat lentil and slightly higher beds of the upper Boquillas-Terlingua unit. In the central part of the quadrangle, the sandstone-breccia-conglomerate includes locally derived angular Aguja boulders and rests on upper Terlingua beds. South of the Fizzle Flat fault, the conglomerate contains many products reworked from the Aguja, and it rests on either the Terlingua-Aguja transition zone or a thin section of Aguja. Near Paint Mountain (SC), the conglomerate rests unconformably on the Aguja and consists almost entirely of materials obtained from the Aguja section.

The typical conglomerate reaches a thickness up to 50 feet in the southwest part of the quadrangle near the Solitario. This suggests that an important contributor of Comanche fragments lay southwest of the Agua Fria area. The Solitario was already a positive element in early Tertiary time and had been eroded deeply enough for the Devils River and Glen Rose to be exposed and furnish materials for the conglomerate. Proof is the marked angular unconformity between the basal Tertiary conglomerate and the underlying Cretaceous west of Hill 4207 (extreme SW). At this locality, the conglomerate rests on a slightly tilted erosional surface that truncates strong east-dipping Devils River, Grayson, Buda, and Boquillas beds.

Exposures along several creeks in the area northwest of Agua Fria Mountain illustrate the irregularity of bottom on which the basal Tertiary conglomerate was deposited (Pl. 4, fig. 3). The resistant conglomerate forms overhanging ledges after the softer underlying Cretaceous strata, such as uppermost Terlingua and basal Aguja, have been eroded. The original broad undulations and pot-hole-like depressions are preserved as casts on the underside of the conglomerate.

TUFFS: The volcanic series above the basal conglomerate is a heterogeneous assortment of materials in which calcareous tuffs predominate. Conglomerates, breccias, sandstones, clay-tuffs, limestones, and lava flows are other constituents. Lenticularity of beds, unconformities, channeling with fill, and facies changes within short distances are common.

The tuffaceous beds in the Agua Fria quadrangle are dominantly white to gray, nodular, calcareous clay-tuffs, but pastel shades of cream, yellow, brown, red, pink, and purple are abundant. Thick, horizontal, brick- to brighter-red and gray bands alternate in the bluffs of Devils Graveyard.

The clay-tuff, especially the gray, is bentonitic in many places and gives rise to the clay balls found in creek beds. Bentonitic clay-tuff sections with few ledges of limestone, sandstone, breccia, or conglomerate produce characteristic whaleback hills (Pl. 3, fig. 1), but resistant beds are almost everywhere interbedded with the tuffs.

$CaCO_3$ supplies much of the cementing material of the tuffs and occurs as relatively rare, dense, limestone beds, generally 1–2 feet thick; zones of nodular limestone; and small nodules of impure limy material dispersed throughout the section. Presumably much of the $CaCO_3$ in the Pruett formation was obtained from the weathering of Cretaceous strata.

Glaring snow-white chalky tuff apparently was deposited as pockets in brick-red, calcareous clay-tuff. A series of these white pockets extends for more than a mile northeastward from Dike 3700 in Devils Graveyard. The alignment suggests faulting, but underlying uninterrupted key beds disprove a possible fault contact of the white and red tuffs.

Very coarse, grayish, sandstone-breccia channel deposits, lenticular in cross section, occur in the western part of the quadrangle, where, because of their resistant nature, they hold up elongate topographic ridges in the tuff section.

In many places intraformational conglomerates in the tuff occur in the form of discontinuous lenses that may be no greater than 1–3 feet thick. Many such conglomerates are composed entirely of well-rounded and highly polished chert pebbles and cobbles, which indicate a great horizontal distance of transport or a lateral reworking for considerable time. Other fragments found in the sandstone-conglomerate lenses are tuffaceous material, limestone pebbles, green chert, and dark banded chert.

In the east-west draw about midway between Agua Fria Mountain and Whistler Squat, a small hill a quarter of a mile east of the road appears yellow-brown from a distance due to the weathering of numerous limonitic and calcareous concretionary structures from a brick-red clay-tuff section. The concretions range up to several inches in diameter, and some have a crude approach to cone-in-cone structure.

In Devils Graveyard, vertical clastic dikes, 1–3 inches thick and composed of angular fragments of varicolored tuffs in a darker matrix, are more indurated than the enclosing tuff and produce minor topographic ridges.

The recent works of Goldich and Elms (1949) and Goldich and Seward (1948) present a detailed description of the tuffs of the Buck Hill volcanic series in their normal stratigraphic sequence. Complex structure, lateral facies changes, and concealed intervals in the Agua Fria quadrangle prevented the tracing of individual beds and, consequently, the building up of a composite section. The following details are from local areas and stratigraphically isolated exposures, but they are presented in supposedly correct ascending order.

Petrified tree trunks are fairly common in the basal conglomerate and the sandstone or tuff that immediately overlies it. Knots, grain of the wood, and annular rings are beautifully preserved in some specimens. Several fossil trees in the vicinity of Hill 3580 (SW) are 50 to 70 feet long.

The lower tuff at several places closely resembles the underlying Aguja formation, particularly the tuff that rests on a coarse-grained sandstone commonly associated with the basal conglomerate. This tuffaceous section, like the Aguja, *is* generally yellow-brown to gray with rusty splotches. The striking similarity of the two formations is perhaps one reason earlier writers assumed a gradational contact between Cretaceous and Tertiary beds. Apparently the Aguja was reworked and redeposited with the basal tuff beds so that the resulting rock is a mixture of Aguja and Tertiary materials. The lower tuff, much of which is high in $CaCO_3$, clay, and sand content, generally is brownish or reddish to white, forms whaleback hills, has thin continuous sandstone beds and lenticular channels of sand, and in some places looks like Aguja that has been reddened by secondary action. The presence of the basal Pruett conglomerate below this questionable section is the most reliable proof that it is Tertiary rather than Cretaceous.

The tuffs exposed on Paint Mountain are relatively low in the Pruett section and are strikingly conspicuous, because the alternating thick, horizontal, reddish and grayish bands contrast sharply with the drab background color of the Aguja as the mountain is approached from the northeast. The tuff is well-lithified and highly calcareous, and large low-spired fossil snails were collected at the northeast base of the mountain. According to Goldich (personal communication), calcareous nodules present here are more numerous and larger than in the corresponding tuff in the Buck Hill quadrangle.

Barite occurs in the lower tuff at a locality 1½ miles west of Paint Mountain on the west bank of a draw that empties into Alamo de Cesario Creek.

Section of lower Buck Hill volcanic series measured on east bank of draw 1-3/4 miles due north of Whistler Squat

	Thickness *Feet*
Quaternary—	
19. Terrace gravel.	6
——————Unconformity——————	
Tertiary—	
Buck Hill volcanic series—	
18. Hard, dirty pink-gray, calcareous sandstone bed; forms prominent ledge	1.5
17. Partially covered, friable, massively bedded, calcareous and tuffaceous silty clay with occasional hard, thin, ledge-forming tuff beds. Broad color bands grade upward from gray to brick-red to light purple to gray. Odd-shaped calcareous nodules weather out on slopes.	63
16. White to light-purple tuffaceous section with beds, 1± foot thick, of hard,	

white, nodular, impure, pitted limestone that weathers rusty brown.	21
15. Very hard, gray to reddish-brown, thick-bedded, calcareous, fine-grained sandstone; weathers to well-rounded boulders.	6
14. Hard to friable, light greenish-gray, massively bedded calcareous sandstone with occasional layers of chert-pebble conglomerate. Unit forms precipitous cliff and varies considerably in thickness	25±
13. Friable to indurated, light-purple, calcareous and tuffaceous beds	5
12. Very hard, white, nodular, impure tuffaceous limestone that weathers rusty brown.	8
11. Alternating calcareous tuffs and calcareous siltstones. Tuff beds average 3 feet thick and are light gray to reddish-lavender. Siltstone beds are hard, white, average 1.5 feet thick, and weather to a rusty color and nodular surfaces.	40
10. Hard, white tuff bed.	0.5
9. Indurated, grayish-white, massively bedded calcareous tuff.	4
8. Hard, white, calcareous tuff bed.	0.5
7. Hard, light grayish-white, massively bedded, noncalcareous tuff.	12
6. Very hard, white tuff bed with small brown concretionary structures.	0.5
5. Hard, rusty orange to reddish-lavender to grayish-white, calcareous, tuffaceous clay with zone of calcareous nodules. Section weathers to whaleback hills with nodules and small cauliflower concretions (caliche?) on slopes.	25
4. Hard, gray-brown, laminated, fine-grained calcareous sandstone beds, 3–4 inches thick, alternate with reddish, calcareous siltstone beds, 1 foot thick. .	7
3. Hard to friable, dingy gray, poorly bedded, coarse-grained calcareous sandstone.	2.5
Total tuffaceous section exposed.	221.5
——————Unconformity——————	
Cretaceous—	
Terlingua beds—	
2. Hard to indurated, gray to rusty yellow, laminated calcareous shale.	±5
1. Bottom of draw.	

Owing to gentle westerly dip, the tuffaceous section in Devils Graveyard is tentatively regarded as middle Pruett. Outcrops in the semicircular hill northeast of Whistler Squat (Pl. 3, fig. 3) illustrate the approach to a provisional age determination of such isolated exposures. A conglomerate that contains many igneous pebbles lenses out completely in places and lies on an unconformity of variable position in the tuff section. The igneous pebbles, some amygdaloidal, indicate that the conglomerate is younger than basal Pruett. Although the tuff above the unconformity or conglomerate is decidedly different lithologically and in bedding from that below, thereby suggesting a younger formation, the entire sequence is probably Pruett, because all the tuffs are calcareous.

A persistent light-colored sandstone marker bed that extends from the northwest corner of the area southward about to the latitude of Burnt House Camp may correspond to the upper [Whirlwind] breccia member of the Pruett formation. The sandstone bed dips gently to the west and is continuous along the west bank of the tributary which flows from the north and empties into Crystal Creek.

With structural conditions for chief evidence, the youngest beds of the Buck Hill volcanic series probably are those in the southwest part of the area just northeast of the Solitario fault. The sequence is:

Tuff
Lava flow
Tuff
Lava flow
Highly colored tuff (50± feet)
Fresh-water limestone (50± feet)
Very coarse yellow conglomerate (200± feet)
Tuff

The brilliantly colored tuff above the limestone displays olive-green, cream, white, light brown, rust, red, purple, and yellowish-green.

WELDED TUFF: At Hill 4014, nearly half a mile southwest of Agua Fria Mountain, the rock that caps the ordinary tuff is a welded tuff resembling rhyolite. Macroscopically the rock appears to be a porphyry with phenocrysts of clear feldspar and quartz set in a salmon-pink aphanitic groundmass. Inclusions of a pumiceous rock, up to 4 inches in greatest dimension, are common.

Thin sections show lune-, cusp-, and bubble-shaped structures in a pasty groundmass. Some of the relict bubble-like structures are collapsed, which suggests that pumice plus heat produced the collapsed pumice effect. The angular shard-like structures, however, are convincing evidence for a pyroclastic origin; and the rock probably is a welded tuff (Mansfield and Ross, 1935) or an incandescent tuff (Fenner, 1948). Because euhedral to subhedral, embayed and corroded crystals of sanidine and quartz, up to 2.5 mm long, and fragments of a pre-existing rock are present in the welded glassy matrix, the rock might appropriately be called a welded vitric-crystal-lithic tuff.

Other outcrops of this rock occur from the Mesquite Tank area northwestward to the point where the Tascotal Mesa fault intersects the west boundary of the quadrangle. Lonsdale (1940, p. 1563) described a welded tuffaceous rock from the Tertiary section southwest of the Solitario. Recent uncompleted work by Goldich, Erickson, and others indicates that rocks of this kind may be widespread in Trans-Pecos Texas.

FRESH-WATER LIMESTONE: Goldich and Elms (1949, p. 1143–1151) pointed out that the Buck Hill volcanic series, although chiefly tuff, includes a subordinate amount of fresh-water limestone. The limestone beds yield fossils well enough preserved to be identified accurately and thereby afford a fairly reliable age determination for the otherwise dominantly clastic Tertiary section.

Limestones of the Buck Hill volcanic series are exposed at a number of isolated localities in the Agua Fria quadrangle. During the summer of 1948, Goldich visited many of these limestones and concluded that all are of fresh-water origin. Most contain a fresh-water fauna, but some are nonfossiliferous. The latter cannot unquestionably be called fresh-water, but their presence in a volcanic section that has yielded land snails and their close association with and lithologic similarity to fresh-water limestone beds are indirect evidence for nonmarine conditions of deposition.

Many of the Tertiary limestone beds are lithologically similar to normal marine limestone but contain the fresh-water genera *Planorbis* (verified by H. B. Stenzel) and *Goniobasis* (verified by Goldich). According to S. P. Ellison (personal communication), the internal molds of ostracodes obtained from a limestone of the Buck Hill volcanic series probably represent fresh-water forms. Goldich and Elms (1949, Fig. 3) list *Goniobasis, Physa, Cochliopa,* ostracodes, charophytes, and algal structures from fresh-water limestones in the Pruett formation; and they find fossil snails scattered in the tuffs of the Pruett and Duff formations.

The hill on top of which is B.M. 3540 (C) is capped by 41 feet of macroscopically nonfossiliferous Tertiary limestone, which rests directly on the Fizzle Flat lentil, here reddish to pink and silty. From a distance, the massive limestone might be mistaken for a reef in the Boquillas-Terlingua sequence. The rock ranges from very dense to a powdery, chalky material. More generally, though, this limestone is hard to very hard, light brown to gray, massively and irregularly bedded; and it contains small amounts of scattered light-brown chert and limonite. A very rough and irregular (karren) weathering surface characterizes the limestone. Some portions of the rock appear brecciated, which may account for the development of a cracked type of weathering. Samples of a white, granular or saccharoidal caliche-like phase of the limestone, common on top of the hill, have a petroliferous odor and possibly contain ostracodes. Many veins of white calcite are present in this circular Tertiary limestone mass, which apparently occupies a small, local, saucer-shaped structural basin, for the Fizzle Flat beds dip under the base of the limestone at all points around the hill. This may, however, be merely the result of settling.

Rocks similar to those just described occur west of Hill 4207 (SW) where a few feet of

Tertiary limestone rests directly on the basal Pruett conglomerate. The limestone contains some chert, exhibits the cracked type of weathering, and closely resembles the Devils River limestone.

A dirty brown limestone bed, 4 feet thick, that yields the best silicified Tertiary fresh-water fossils in the area, caps a section of white to light-gray calcareous tuff in a small hill just north of the road 2 miles north-northeast of Burnt House Camp (NW). Several other outliers of hard, white to brown fresh-water limestone occur in the fault blocks southeast of this locality and east of Burnt House Camp. Light-gray to light-brown chert and gray-brown flint are present in some of these resistant limestone beds, which average 2.5 feet thick. Many beds weather to nodules and boulders, and some are fossiliferous.

Section measured on south face of small hill northwest of broad right angle curve in road 2 miles north-northeast of Burnt House Camp

	Thickness *Feet*
Buck Hill volcanic series—	
5. Very hard, brownish-gray to brown, thick bed of fresh-water limestone. Contains chert, flint, and silicified fossils (*Goniobasis* most abundant, *Planorbis,* ostracodes). Weathered rock is brown, has a cracked appearance, and breaks down to very angular fragments.	4
4. Covered (apparently same as 2)	34
3. Hard, white to light-gray fresh-water limestone bed. Weathers to very nodular surface and contains brown chert. Fossiliferous	2.5
2. Friable, light-gray, massively bedded clayey tuff. Slope weathers to nodular surface................................	13
1. Valley flat.	

A nonfossiliferous Tertiary limestone, probably the same as that at Hill B.M. 3540 (C), caps Hill 3546, 1½ miles to the southeast. If these two limestones could be proved correlative, the date of faulting in this locality could be determined more accurately. The diastrophic history of this area is discussed later.

Section measured at southeast end of Hill 3546 (C)

	Thickness *Feet*
Tertiary—	
Buck Hill volcanic series—	
7. Hard, snow-white to brown, massive and irregularly bedded nonfossiliferous limestone. Smooth-textured to granular, karren and cracked weathering, small amounts of limonite and chert...........	40±
6. Partially covered slope of reddish tuffaceous section...........................	38
5. Hard, rusty gray to gray, massive and cross-bedded calcareous sandstone-breccia..................................	20
4. Indurated to friable, gray to yellow, massively bedded tuffaceous marl with dull brick-red splotches. Hard irregular nodules weather out....................	25
3. Basal Tertiary conglomerate: Hard, yellowish-gray conglomerate beds, 3± feet thick, consist of well-rounded limestone and chert pebbles (up to 4 inches in greatest dimension) cemented in a calcareous sandy matrix. These alternate with hard to friable, yellow-gray, cross-bedded, coarse-grained calcareous sandstone beds, 2± feet thick. Limonitic zone occurs 2 to 3 inches above disconformity, and *Inoceramus* prisms common in this conglomeratic section............	16
Unconformity	
Cretaceous—	
Terlingua beds—	
2. Indurated to friable, gray to cream-yellow, laminated calcareous shale. Weathers to small splinters and biscuit-shaped nodules. Limestone beds, about 6 inches thick, widely spaced.......	57
1. Top of Fizzle Flat lentil (?).	

A nonfossiliferous Tertiary limestone, which contains pebbles of black chert, caps the tuffs that form the south bank of an easterly sloping draw at a point west of the road and 2 miles northwest of Agua Fria Mountain. Another nonfossiliferous limestone is present in the Tascotal Mesa fault zone 1 mile east of the west boundary of the quadrangle where a bed about 3 feet thick caps the tuffs in a small hill.

The thickest development of limestone in the Buck Hill volcanic series (Pl. 4, fig. 2) occurs in the conglomerate, tuff, and lava flow sequence just northeast of the Solitario fault (SW). This limestone section, which is approximately 50 feet thick and thins somewhat to the northwest, rests on a section of yellow conglomerate some 200 feet thick. The impure granular or saccharoidal limestone is indurated to hard, yellow-gray, thin and irregularly bedded. Imperfect karren, pitted, and cracked types of weathering prevail. The limestone contains geodes, algal structures, and angular black chert pebbles. The latter resemble the bedded cherts of the Ordovician Maravillas formation, which is exposed in the Solitario and may have been the source of the black fragments. Cave-type deposits form where there are overhanging ledges of the limestone. The rock disintegrates into small angular fragments that make steep dip-slopes difficult and dangerous to walk on; the dips in this area average 25° to the southwest. Certain zones carry finely disseminated dark-brown chert in thin, irregular layers, some of which contain algal structures.

YELLOW CONGLOMERATE: A thick yellow conglomerate crops out in a band in the downthrown (northeast) block of the Solitario fault, and this band parallels the fault for almost its entire length in the quadrangle. The rocks here are among the youngest Tertiary exposed in the quadrangle, and probably the conglomerate is near the top of the Pruett. The conglomerate, apparently a local development around the periphery of the Solitario, is overlain by limestone, tuff, and lava flows. The 50 feet of limestone resting on the conglomerate strongly suggests that the latter is part of the Pruett formation.

The yellow conglomerate varies considerably in thickness. From exposures in the vertical walls of a huge plunge basin in the area southwest and west of Hill 3963, the thickness was estimated at 200–300 feet. The conglomerate, like the limestone, tuff, and lava flows of this sequence, thins to the northwest so that it is probably no more than 100 feet thick at the west boundary of the area.

The basal portion of the conglomerate, which rests on a wavy and channeled surface of the underlying tuff, consists primarily of fairly well-rounded igneous boulders that average a foot in diameter, but some up to 4 feet were observed. Local lenses have a high percentage of angular boulders and should be termed breccia-conglomerates. Limestone boulders, some of which contain black (Maravillas?) chert, are also present.

The conglomerate in the vicinity of Hill 3951 and Hill 3802 is loose to indurated, yellow, and massively bedded. The matrix is a fine-grained yellow sand with much gypsum and other efflorescences. Pebbles, cobbles, and boulders consist of angular igneous rocks to well-rounded limestones. The size range is from that of a small pebble to boulders 3± feet in diameter. The fragments consist of Comanche limestones with silicified fossils, fine-grained dense to vesicular acidic igneous rocks, quartz, black Maravillas (?) chert, Caballos (?) novaculite, green and brown cherts, and banded cherts. These suggest local derivation from the Solitario, which lies to the southwest; and the angular chert and novaculite fragments impart a Paleozoic aspect to a weathered surface of the conglomerate. On relatively flat weathering surfaces, brecciated sponge-like caliche deposits, 3 ± feet thick, occur locally.

PLATE 4.—BUCK HILL VOLCANIC SERIES

FIGURE 1. VIEW SOUTHEASTWARD ACROSS THE TUFF SECTION OF DEVILS GRAVEYARD TOWARD AGUA FRIA MOUNTAIN

Dike 3600 in foreground. (Photograph by R. B. Davis.)

FIGURE 2. FIFTY-FOOT SECTION OF FRESH-WATER LIMESTONE UNDERLAIN BY YELLOW CONGLOMERATE AND OVERLAIN BY TUFF AND LAVA FLOWS

Dip is southwest toward Solitario fault.

FIGURE 3. CRETACEOUS-TERTIARY CONTACT

Basal tertiary conglomerate was deposited on irregularly eroded Terlingua beds in southwestern part of quadrangle.

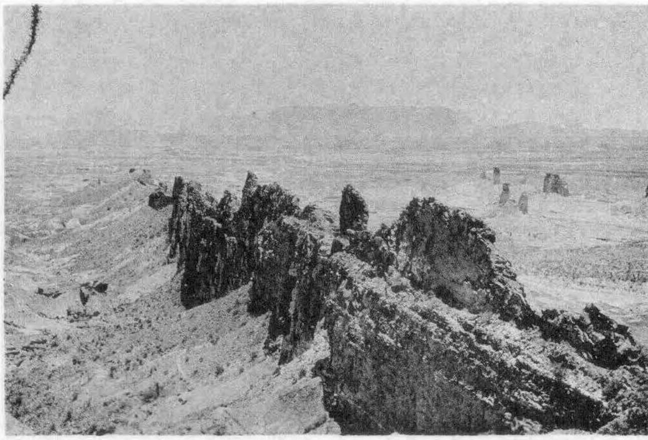

FIGURE 1

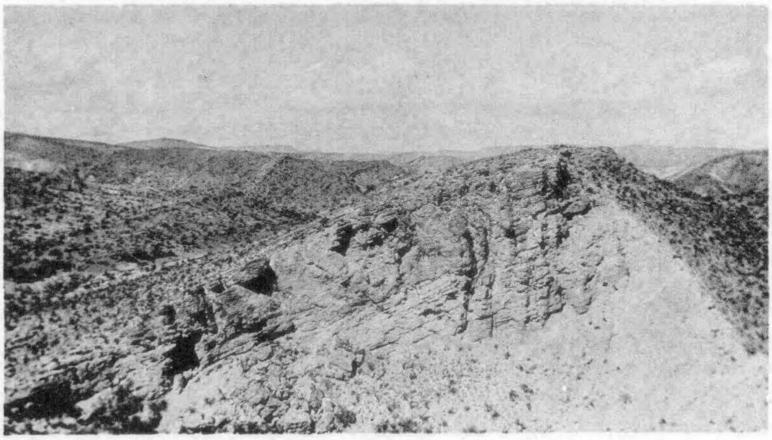

FIGURE 2

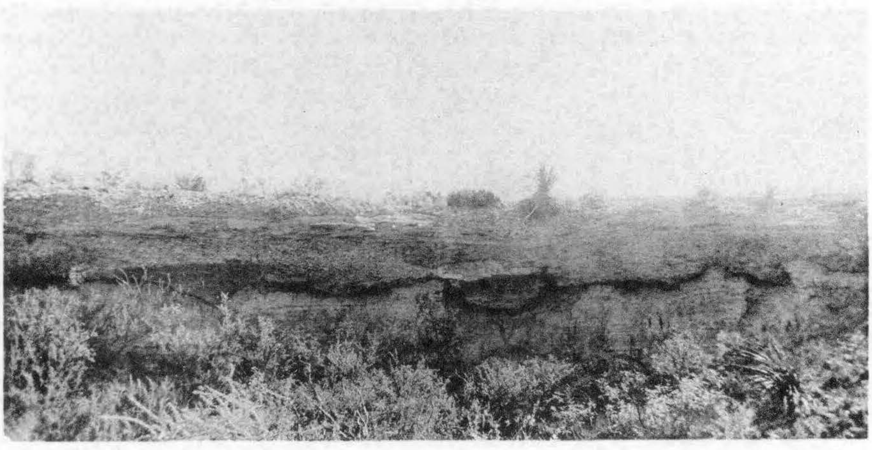

FIGURE 3

BUCK HILL VOLCANIC SERIES

In most places the conglomerate rests directly on ordinary tuff. However, at a point a mile due west of Hill 3963, marked by the intersection of southeasterly and northeasterly sloping draws and in the southeast bank of the latter, a welded tuff averaging 10 feet thick lies between regular tuff below and the yellow conglomerate above. The welded tuff dips upstream (southwest) toward the Solitario, and within a quarter of a mile it is both overlain and underlain by the yellow conglomerate. These conditions suggest that the Solitario was rejuvenated while the yellow conglomerate was being deposited and that the doming of the Solitario proper was accompanied by a periphery collapse in which the conglomerate accumulated as boulders were shed from the Solitario dome. Then the welded tuff was formed on top of ordinary tuff to the northeast, but to the southwest it accumulated on the lower portion of the conglomerate already deposited nearest the Solitario. Later a great thickness of the yellow conglomerate was deposited above the welded tuff. Materials in the conglomerate indicate Paleozoic, Comanche, and igneous sources. Because these rocks are exposed in the Solitario, it is a likely source area. The decrease in fragment size from bottom to top, illustrated by gradation from very coarse basal material to the uppermost sand and finer breccia-conglomerate, suggests that the Solitario was being worn down during the accumulation of the yellow conglomerate.

LAVA FLOWS: Intercalated lava flows are an integral part of the Buck Hill volcanic series. Sheetlike igneous masses are common in both Cretaceous and Tertiary strata of the area, but most tabular igneous masses in the Cretaceous, whether deroofed or covered, are sills, whereas those in the Buck Hill volcanic series are mostly flows. Probably all igneous rocks in the Agua Fria quadrangle are of Tertiary age.

Two trachyte flows separated by tuff cap Paint Mountain. Both exhibit flow structure, and both include basal flow breccias preserved in old channels in the tuffs under the flows. The upper reddish-brown flow is vesicular, and some of the vesicles contain calcite amygdules.

Two flows at a higher stratigraphic position are separated by conglomeratic tuff and are faulted down against the Boquillas along the Solitario fault. The northwest-southeast extent of these outcrops is some 2½ miles. The lower flow is a vesicular trachyandesite or andesine trachyte with agate amygdules. The higher flow is a more dense analcimitic diabasic microgabbro with vesicular and amygdaloidal portions.

Basic analcime-bearing rocks occur as flows in the volcanic section at Hill 3494 (SC) and in the area southwest of Agua Fria Mountain.

FOSSILS: The only fossils obtained directly from the tuff are several internal molds of a low-spired *Helix*-like gastropod. The largest specimen is 1-3/4 inches in diameter, 1 inch high, and consists of 4 whorls. The snails were collected from white, nodular, calcareous tuff beds at the northeast base of Paint Mountain. These beds probably occupy a lower Pruett stratigraphic position, for, although the interval between the two localities is covered, the basal Pruett conglomerate crops out in the bed of Terlingua Creek about a quarter of a mile east of this fossil locality, and the east-west dip component between the two points is slight.

Limestones, where fossiliferous, are the most prolific fossil beds of the Buck Hill volcanic series. Well-preserved specimens of silicified forms were collected from the limestone that caps the small hill just northwest of the road and 0.4 mile northwest of Hill 3550 (NW). The white fossils stand out in relief on surfaces of the hard, dark-brown limestone. Although small, the gastropods are conspicuous by color contrast. An insoluble residue of this limestone contained:

Goniobasis sp.
Planorbis sp.
Internal molds of ostracodes

Goniobasis and *Planorbis* are listed as nonmarine mollusca by Henderson (1935); and according to S. P. Ellison (personal communication) the ostracodes are probably fresh-water forms. A hard, light-gray, chert-bearing 2.5-foot thick bed of fresh-water limestone, 34 feet below the bed just described, contains numerous *Planorbis* sp. The largest specimen found is 0.2 inch in diameter.

Several other hard, light-gray limestone beds in the northwest part of the quadrangle, and particularly the steeply dipping bed just north of the road and in the fault zone at a point almost three-fourths of a mile due south of Long Hills, yield numerous *Planorbis* sp. These forms are preserved as casts of clear to brown calcite. The largest specimens reach half an inch in diameter and consist of 6 or 7 whorls. These beds are low in the Buck Hill volcanic series, probably lower Pruett.

Limestone beds from a high (?) stratigraphic position in the Pruett (?) formation in the area just northeast of the Solitario fault contain algal structures that average half an inch in diameter.

STRATIGRAPHIC RELATIONS: Goldich and Elms (1949, p. 1143–1145) tentatively assign the Pruett formation to the Eocene on the basis of abundant specimens of *Goniobasis* collected from limestone lentils in the upper part of the formation. They assign the Duff formation to the Oligocene on the basis of a smaller gastropod. Because the Buck Hill volcanic series of the Agua Fria quadrangle can be correlated with that of the Buck Hill area, the next quadrangle to the north, the Tertiary volcanic rocks of the Agua Fria quadrangle are likewise tentatively assigned to the Eocene-Oligocene.

The basal conglomerate of the Buck Hill volcanic series in the Agua Fria quadrangle everywhere rests unconformably on Cretaceous strata. A relatively thin (Quaternary?) gravel cover unconformably caps the tuffaceous series in several large areas.

Quaternary

General description.—Deposits of Quaternary age in the Agua Fria quadrangle include older gravels that stand at higher altitudes in the western part of the area and alluvium or valley-fill found at lower elevations in the eastern part of the quadrangle. The two were mapped as separate units.

Gravel.—The Quaternary (?) gravels consist chiefly of fairly well-rounded cobbles and boulders of igneous rocks that occur in relatively thin, almost flat-lying sheets at different elevations. Three distinct gravel-covered rock terraces can be seen west of Terlingua Creek near Clanton ranch. The approximate locations and elevations of the three main terraces are:

Terrace	*Approximate distance west of Clanton ranch*	*Approximate elevation, feet*
I	1¼ miles	3300
II	½ mile	3250
III	¼ mile	3200

As a reference surface, the elevation of the present flood plain of Terlingua Creek, less than a quarter mile west of Clanton ranch, is about 3175 feet.

The oldest gravels cap Long Hills (NW) at an average elevation of about 3700 feet. Green Valley or Greasewood Flat, the most widespread gravel-covered surface in the northwest part of the quadrangle, averages about 3550 feet in elevation. The youngest terrace, about 25 feet lower than Greasewood Flat, parallels the present course of Terlingua Creek and is relatively narrow. This youngest gravel deposit, which can be called the Burnt House Camp terrace, is some 25 feet higher in elevation than the present flood plain.

Apparently Green Valley, which is now being dissected by Terlingua Creek and its tributaries, is an extensive pediment that developed as Bandera Mesa, in the Tascotal Mesa quadrangle to the west, retreated westward during an earlier erosion cycle. Perhaps the Long Hills surface is the only surviving remnant of a still older pediment. The lower terraces along Terlingua Creek probably represent slight local uplifts or lowerings of base level. They are of less magnitude and significance than the Long Hills and Green Valley pediment gravels, and they are not everywhere gravel covered.

Alluvium.—The material mapped as alluvium in the eastern part of the quadrangle is primarily valley-fill, much of which has probably been deposited as sheet-wash. The material is considerably less coarse than the igneous gravel, and its composition is principally that of the near-by sedimentary rocks. Undoubtedly it is of much more recent origin than the gravels at higher elevations to the west. That part of Hale Draw north of Dewees Tank (NE) is now dissecting a cream-brown alluvial fill, the upper 5 feet of which is fine-grained and fairly well bedded. The lower part contains a higher percentage of caliche and a greater number of Boquillas limestone pebbles than the upper 5 feet.

INTRUSIVE IGNEOUS ROCKS

Introduction

Lonsdale (1940) described the chief igneous masses in the southern part of the Agua Fria quadrangle and located them on a regional reconnaissance map. Plate 1 shows more structural detail around the intrusive masses, and the following paragraphs supplement Lonsdale's work and the sections on igneous petrography and structure of this paper.

The hypabyssal intrusive igneous rocks of the Agua Fria quadrangle occur as ruptured laccoliths, stocklike bysmaliths (?), cores of trap-door domes, plugs, dikes, and sills. The rocks range in composition from soda rhyolites to picritic basalts and include an analcime-bearing series. Many of the intrusive masses are so closely interrelated with structure that to discuss the two independently is impractical. This is particularly true of the trap-door domes, which hold the key to the understanding of several of the more important intrusives.

Trap-door Domes

Trap-door domes are a combination of an unique igneous mode of occurrence and faulting. Knechtel (1944) describes domes with a central trap-door block as follows:

> "The subordinate domes ... were formed by bodies of igneous rock which were punched upward into the sedimentary rocks. They range in diameter from 1½ to 3½ miles. Each is typically subcircular or subelliptical in plan and normally includes a hinged block that is raised on a nearly vertical fault of curved trace. The rock strata in such a block are tilted up like a trap-door which has opened along the fault and slopes down toward the opposite side of the block."

Gray Hill (SE) is the best example of this unusual structure in the Agua Fria quadrangle (Fig. 3). Here the uplifted, rectangular trap-door block, which is elongated in a northwest direction, dips to the northwest toward the hinge and is bounded on the other three sides by relatively straight faults that intersect almost at right angles. The two parallel faults are called paired faults, and the one fault at the southeast end, parallel to and opposite the hinge, is referred to as the unpaired fault. The latter has the greatest throw, and both paired faults decrease from a maximum throw at their intersection with the unpaired fault to zero at the hinge. Although no igneous rock is exposed at Gray Hill, a bysmalith-like intrusive mass is postulated to explain this special type of dome. Relationships between exposed igneous masses and other similar, though not so perfectly developed, trap-door domes support this assumption. Devils River, Grayson, Buda, and Boquillas crop out in the tilted trap-door block, but the flanks of the dome consist principally of Boquillas flags.

Red Bluff, a domical uplift along the east margin of the area, is similar to the domes described by Knechtel except that faulting, which must have occurred on the northwest flank, is obscured by the soda trachyte intrusion. The red bluff is a narrow crescent-shaped wall that terminates the dome to the northwest. The vertical wall, which resembles a ring-dike, towers 700 feet above the surrounding flat and stands 350 feet higher than the deroofed portion of the laccolithic intrusion. Presumably as the dome was being arched by the injection of viscous magma, its northwest flank fractured and an arcuate fault resulted. Being a line of weakness, the fault offered a means of escape for the magma, which, possibly aided by stoping, moved upward and thereby formed the mass that now stands as a towering semicircular wall after the previously enclosing sedimentary rocks were eroded. That part of the Boquillas roof rock nearest the concave or southeast side of the bluff has been stripped so that crude, vertical columnar jointing in the laccolith (?) proper is revealed, and Boquillas beds 40–50 feet above the igneous-sedimentary contact have been altered by the intrusion. Apparently the ruptured Red Bluff dome results from a partially deroofed laccolithic intrusion, and it strongly resembles a trap-door dome.

Panther Mountain (Pl. 2, fig. 3), a dome with highly faulted flanks, is not strictly a trap-door dome, but it evidently passed through such a stage at one time. Its only difference from a typical trap-door is the presence of an additional fault where the hinge-line should be. The north and west walls of this partially deroofed stocklike soda rhyolite mass are essentially vertical. The upper Devils River caps the southern portion of the intrusion and dips so steeply in a southerly direction that Grayson, Buda, and lower Boquillas flags are preserved only at the extreme south edge of the mountain. With Panther Mountain punched up through its center, the dome takes on the aspect of a stocklike bysmalith. The steep southward tilt of the block suggests that the upward-moving

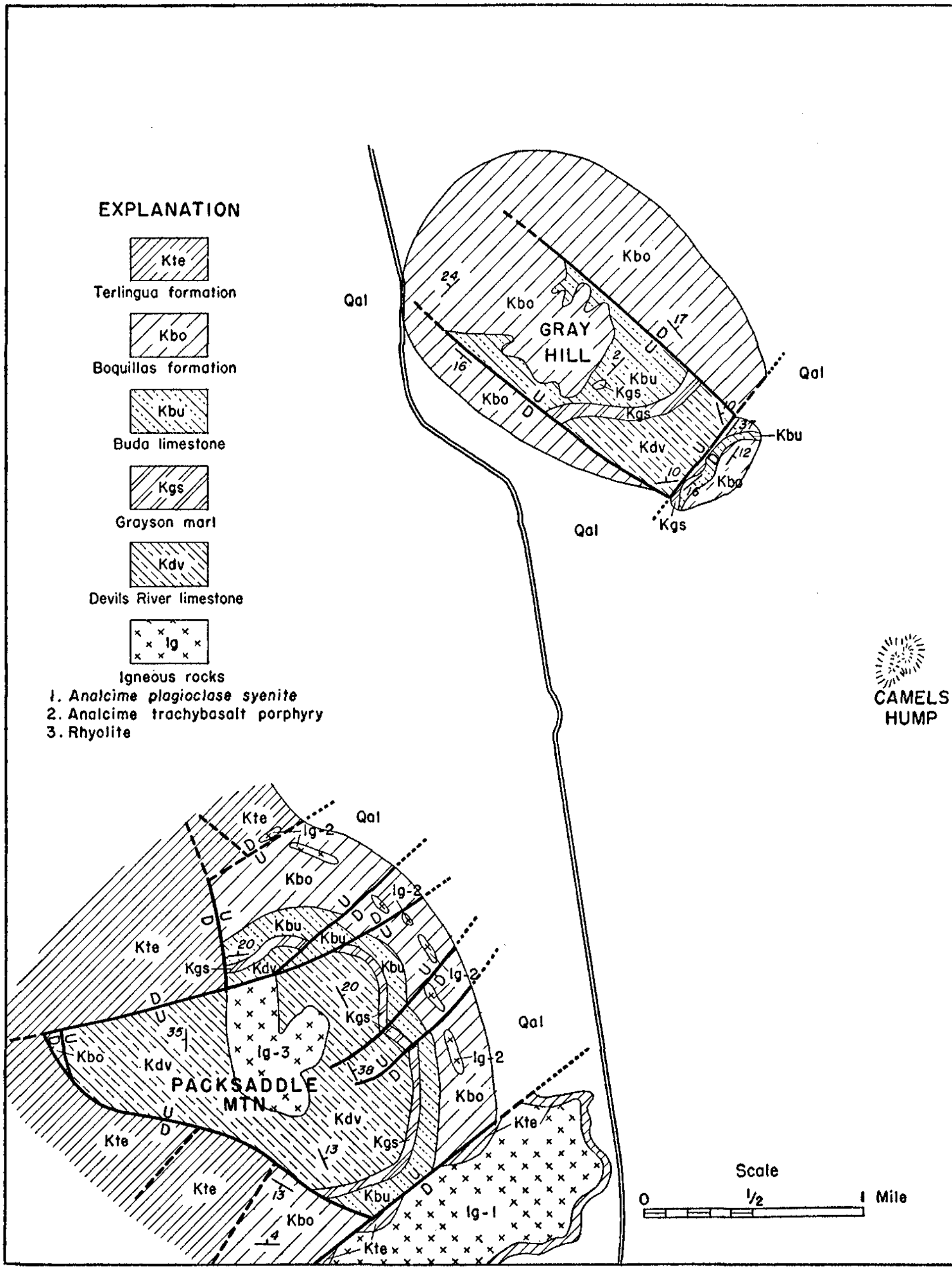

FIGURE 3.—TRAP-DOOR DOME, GRAY HILL, AND DOMICAL UPLIFT, PACKSADDLE MOUNTAIN

magma at first lifted only one end of the block and thereby formed a trap-door, but eventually the pressure became so great that the hinge-line also fractured and the entire block was lifted vertically, though differentially.

Stocks, Laccoliths, Bysmaliths, Plugs, Etc.

The largest single body of igneous rock in the quadrangle is the soda-rich rhyolite of Agua Fria Mountain, a stocklike mass which is about

2 miles in diameter and towers 1500 feet above the average level of the surrounding country. The walls of the mountain are so steep, vertical, or overhanging that they suggest the magma pierced the sediments in a very pasty or semi-solid state. Huge, irregular vertical columns of the reddish-weathered soda rhyolite stand as precipitous cliffs around the periphery of the mass. The most prominent overhanging cliff rises 350 feet above Agua Fria Spring, the water of which emerges from Aguja sandstone pulled up as a narrow fault block that fringes the west side of the mountain. The rhyolite top of the mountain weathers into plates that clink when walked upon.

Although Agua Fria Mountain consists of many peaks, all have practically the same elevation, which suggests that the stocklike mass was originally relatively flat-topped. Perhaps the peaks represent almost the highest elevation reached by the rhyolite. No sedimentary rocks are now present on top of the mountain, but comparison with structurally similar Panther Mountain to the east suggests that Devils River limestone was the roof rock.

Plate 1 indicates that Agua Fria Mountain, the center about which Tascotal Mesa fault and others curve, was instrumental in the development of structure in the south part of the quadrangle. Lonsdale (1940, p. 1555) classifies Agua Fria Mountain, along with similar masses, as a thick uncovered laccolith or bysmalith. The writer favors the idea of a bysmalith and postulates that the possible laccolithic portion of the mass extends to the northeast almost as far as Tascotal Mesa fault. If Agua Fria Mountain proper is only the stocklike portion of a more extensive igneous mass, then the entire structure is a bysmalith rather than a simple laccolith.

The contour map reveals a series of concentric rings of topographic highs and lows on top of Agua Fria Mountain that suggests a cylinder-and-piston effect or a telescopic manner of magmatic emplacement. This postulates that the outer shell cooled more rapidly, owing to contact with bed-rock, became more viscous and acted as a cylinder in which the hotter and more mobile interior piston could still move upward. The zone between the outer cylinder and the inner piston would, under these conditions, be subjected to considerable strain. Hence these rocks would be weakened, would erode more easily, and topographic lows would result. The ring of highest peaks around the periphery of the mountain corresponds to the postulated outer cylinder; the ring of topographic lows inside the peaks represents the rocks supposedly subjected to greatest stress, and the remaining central portion represents the piston.

Packsaddle Mountain is a complexly faulted dome in which an irregularly shaped quartz-poor rhyolite plug has punctured the roof. It is possibly a laccolith or bysmalith. Either the magma of the Packsaddle Mountain plug was differentiated into a core and an outer shell with an intervening transition zone, or the cylinder-piston or telescoping effect proposed for Agua Fria Mountain also operated here and resulted in three different phases of the rock on top of the plug. Most fresh specimens of the rhyolite are grayish-brown to pink, porphyritic, and exhibit swirls. Columnar jointing is well developed in the dense shell rock, which weathers to dark reddish-brown and commonly has a coat of desert varnish. The core rock exhibits excellent vertical and colored flow bands and weathers to huge light-brown boulders. The intermediate or transition zone is reddish and less dense than either the inner piston or outer cylinder. A fourth type of rock, a tightly cemented agglomerate or breccia that occurs as huge boulders in the saddle of the mountain, is probably a remnant of volcanics.

There are several pluglike masses in the southern part of the quadrangle, the most prominent of which are Camels Hump, Hill 4142, a black hill southwest of Packsaddle Mountain, Hill 4302, and possibly the circular mass just south of Agua Fria Mountain.

Bed-rock outcrops are poor around Camels Hump. Due to the rhyolite intrusion, which shows vertical flow structure, the Boquillas-Terlingua blocks exposed on the east side are badly broken. Effects of metamorphism appear to be slight, although some baked limestone is present in the saddle. Remnants of a basic sill, also intruded by the plug, cap basal Terlingua (?) beds and form a small discontinuous bench on the east flank of the hill.

The trachyte plug that forms Hill 4142 (SE) has intruded a down-dropped block of Aguja sandstone. The throat rock is porphyritic with glassy phenocrysts set in an aphanitic groundmass, has excellent flow structure, weathers to reddish-pink, and in many places exhibits a coat of desert varnish. An intrusion breccia occurs around its periphery, and well-developed columnar jointing is present on the southeast side of the hill.

The plug of picritic basalt that forms the small black hill southwest of Packsaddle Mountain has another set of joints normal to the well-developed columnar jointing. This causes the columns to break down into thin hexagonal plates. The fine-grained rock is heavy, dense, black, weathers rusty gray to reddish-brown, and contains visible olivine crystals.

Hill 4302 just south of Panther Mountain is a pluglike intrusion of soda rhyolite very similar in composition to that of Agua Fria Mountain. Huge columns form vertical cliffs, and a vertical parting, suggestive of flow structure, causes the rock to weather to thin plates that clink loudly when walked upon. The rock also shows concentric banding or swirl structures. The mass on the north flank of Hill 4302, which consists of fragments derived from the plug and tightly cemented with ferruginous cement, may be a Recent breccia. Another smaller mass just west of the hill is a tuffaceous breccia, possibly a remnant of the volcanic series.

Poor exposures around the base of the almost circular hill just south of Agua Fria Mountain make it difficult to determine whether this mass is a thick deroofed sill or a plug. In shape and development of massive columnar jointing, the intrusive resembles a plug; viewed from a distance, Terlingua beds appear to underlie the igneous rock. Thin horizontal plates weather from the upper surface of the mass and suggest horizontal flow structure, which evidence favors a sill. The dark-gray to black, heavy, dense, fine-grained rock has a reddish-brown weathering surface, and harder, lighter-colored elliptical pellets, up to 2 inches in maximum diameter, weather from the rock.

A small trachyandesite plug, half a mile southwest of Panther Mountain, occurs in a minor fault zone and consists of a badly brecciated mass of cream-gray to pink fragments cemented with ferruginous material. Calcite veins and small vugs are common. Perhaps the rock exposed is an intrusion breccia.

Sills

Several basic sills with a feeder dike are exposed in the 400-foot west canyon wall of Terlingua Creek a mile west of Panther Mountain; Hill 3450, which tops the cliff, was named Sill Hill. Another combination feeder dike and sill occurs just outside the southwest corner of the quadrangle. Locations of several more extensive sills, most of which are uncovered, and the formations in which they occur are:

Sills	*Formation*
Black Hill	Terlingua
Red Bluff	Boquillas
Pitahaya Hills	Aguja
Hill 3604 (SE)	Terlingua
Hill 3683 (SE)	Terlingua
Area southwest of Agua Fria Mountain	Terlingua

Dikes

The dikes in the western part of the quadrangle have a northwesterly trend which parallels that of the major structural features. Those of the central part of the quadrangle, however, are aligned in a northeasterly direction at right angles to structural trends. All dikes in the area are practically vertical, and none is more than a few feet thick. The longest dike, on Fizzle Flat, extends over 2 miles to the northeast. The highest dikes, those in Devils Graveyard (Pl. 4, fig. 1), stand 200–300 feet above the surrounding country.

Metamorphic Effects

The effects of contact metamorphism are relatively slight, even in the largest igneous occurrences. Noticeable effects on the enclosing country rock generally consist of no more than slight baking plus some color change a few feet from the igneous contact. Little, if any, mineralization of the country rock is apparent at most places.

IGNEOUS PETROGRAPHY

A number of igneous rocks in the southern part of Agua Fria quadrangle and in Brewster

County were described by Lonsdale (1940) and Lonsdale and Dickson (1948). Microscopic studies of additional rocks from the area by the writer are conveniently summarized in a paragraph from Lonsdale (1940, p. 1541):

"The igneous rocks include an analcite-bearing series and intermediate, trachytic, and rhyolitic types, most of which are soda-rich. The analcite-bearing types range from melanocratic gabbroid to syenitic types. Analcite is primary, deuteric, and hydrothermal and was formed through a rather long period. The complete assemblage is alkaline and resembles the suites from Spanish Peaks, Colorado, and other alkaline subprovinces along the front of the Rocky Mountains."

The petrography of the Agua Fria rocks is presented in Table 1. Lonsdale's (1940, p. 1601) special classification for the analcime-bearing rocks, which are such an important group in the Alpine-Terlingua area, adapted from Niggli (1931), is used. Grouping into families, such as microgabbros and basalts, on the basis of grain size is after Hatch and Wells (1937, p. 155, 201).

STRUCTURAL GEOLOGY

General Description

Regional structure in the Big Bend establishes the local structural pattern of the Agua Fria quadrangle (Fig. 4). Approximately 10 miles northeast of the quadrangle are the Santiago Mountains, the northwest continuation of the Sierra del Carmen that lies some 30 miles to the east. This chain forms the easternmost front range of the Rocky Mountains in Texas. The northeast flank of the circular Solitario dome, structurally the highest part of the broad anticlinal Solitario uplift that extends southeastward to Terlingua, lies in the southwest corner of the quadrangle. Between these two positive elements, the Solitario to the southwest and the eastern front of the Rockies to the east and northeast, lies the Agua Fria quadrangle, which, as a whole, is structurally low, due principally to almost vertical normal faults.

Generally, the area is part of the great sunken block described by Udden (1907b) and Baker (1935a). According to Udden (1907b, p. 80–81), a part of the sunken block lies in that area bounded on the east by the front ranges of the Rocky Mountains, on the west by the Santa Elena fault scarp, on the south by the Rio Grande, and on the north by the igneous Corazones and Rosillos mountains, which lie east of and approximately at the same latitude as the south boundary of the Agua Fria quadrangle. The sunken block measures 39 miles from east to west, has dropped 4000–6000 feet structurally, and is extensively faulted and folded. Baker (1935a, p. 174) wrote: "Only exceptionally are the strata in the Big Bend sunken block horizontal. Dips more frequently are from 10° to 30°." Domes, laccoliths, and other intrusive masses are common in the sunken block.

Lonsdale (1940, p. 1543) stated that "to the northwest the settling decreases and ends with the Solitario uplift. . . ." The present detailed mapping shows, however, that a portion of, or an adjustment to, Udden's sunken block extends northwestward into the Agua Fria quadrangle and forms a constricted northwest-trending component of the tremendous negative structural unit. Possibly the sunken block dies out to the northwest within the Agua Fria quadrangle. On the other hand, although narrowed and restricted within the quadrangle, the change in fault trends suggests that the block continues on to the west and northwest in a wider belt outside the mapped area. Baker (1935b, p. 380) expressed the opinion that the Big Bend sunken block extends northward as far as the southern part of Green Valley (NW).

Lonsdale (1940, p. 1543) described the Sierra del Carmen as "a broad step-faulted domical uplift." Similar step faults prevail in the Agua Fria quadrangle, especially in its northeast half, where faults such as the Old Stage Stand, Hale Cabin, White Trail, and Cheosa Waterhole are each downthrown to the southwest and express themselves as prominent southwest-facing fault scarps with the huge fault blocks tilted gently to the northeast. Generally the faults are aligned in a northwesterly direction except in the vicinity of Agua Fria and Packsaddle Mountains, where intrusive masses have modified the trend of near-by faults.

Although no Palezoic rocks are exposed in the Agua Fria quadrangle, the older geosynclinal facies undoubtedly underlies the Cre-

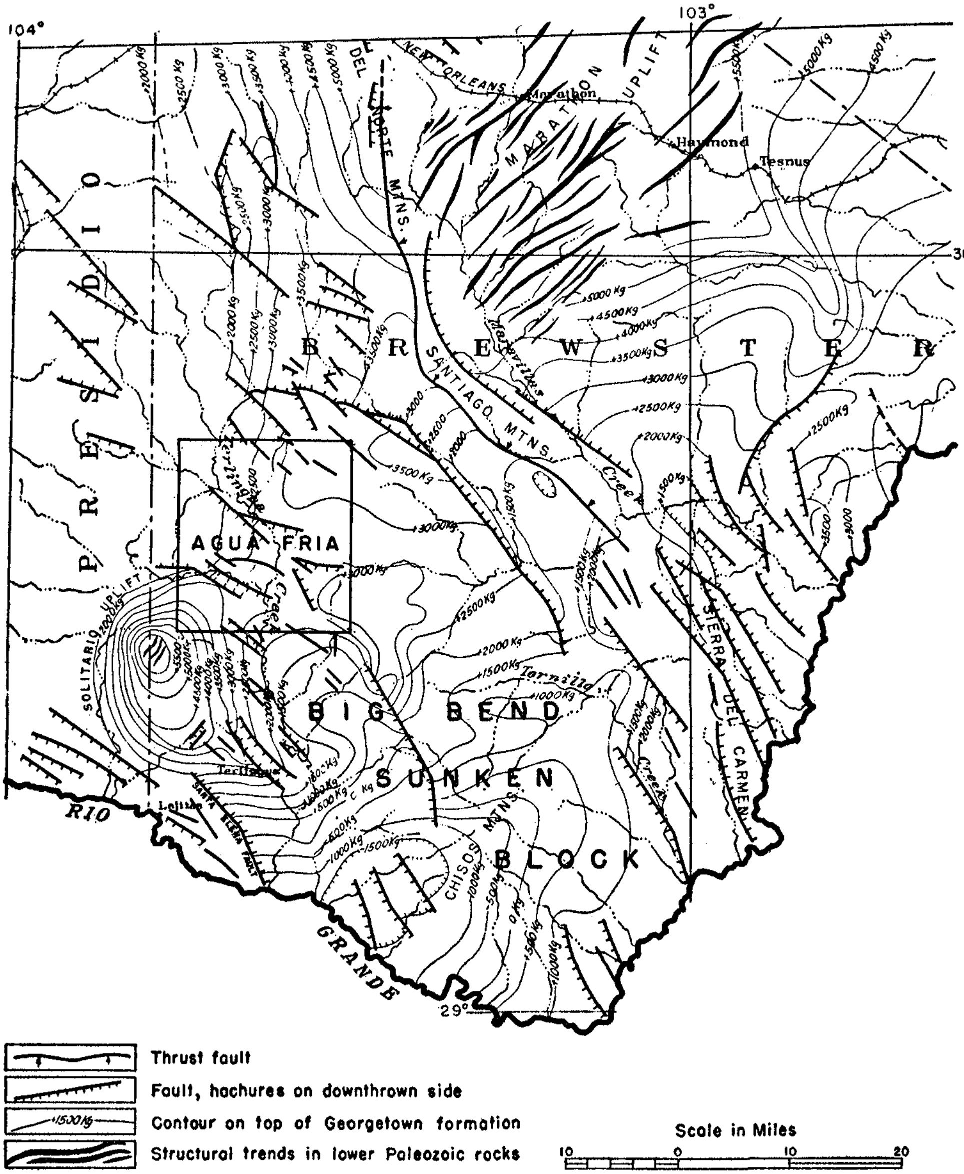

FIGURE 4.—STRUCTURAL SETTING OF THE AGUA FRIA QUADRANGLE
Modified from Structural Map of Texas, 3rd edition, by Sellards and Hendricks (1946).

taceous rocks of the area. Highly folded, faulted, and even overthrust Paleozoics with a northeasterly trend are exposed in the Solitario dome, just beyond the southwest corner of the quadrangle, and in the southwest end of the Marathon uplift about 10 miles northeast of the quadrangle. An angular unconformity separates the Paleozoic and Cretaceous rocks in both areas. The projection of the Paleozoic trends indicates that the Cretaceous rocks of the Agua Fria quadrangle rest directly, but with angular unconformity, on the Ouachita facies, and that the quadrangle probably marks the position of the buried Marathon geosyncline. There is no structural evidence for the old Marathon geosyncline within the Agua Fria quadrangle, for the northwest structural trends in the surface rocks are at right angles

TABLE 1–PETROGRAPHY OF THE IG

LOCALITY	ROCK	OCCURRENCE	DIMENSIONS	TEXTURE	QUARTZ	FELDSPAR		PYROXEN
						ALKALI	PLAGIOCLASE	
Camels Hump	Soda (?) rhyolite	Plug	Diameter: 1/4 mile	Fine-grained, subequigranular	Scattered grains (0.1± mm.)	Abundant laths and stubby xls. (0.1± mm.)		
Packsaddle Mountain	Soda (?) rhyolite (quartz poor)	Plug	Diameter: 1/2 mile	Fine-grained, porphyritic (trachytic)	5% interstitial	88% anorthoclase phenocrysts (3 x 1 mm.) and groundmass laths (0.2± mm.)		
Panther Mountain	Soda rhyolite	Partially deroofed trap-door intrusive	Diameter: 1 mile	Fine-grained, porphyritic (subtrachytic)	Obscure in grd. mass. Rare corroded phenocrysts.	Anorthoclase phenocrysts (4± mm. long). Alkali laths 0.1± mm.		Trace aegirite-augite (?)
Hill 4302 (SC)	Paisanitic riebeckite soda rhyolite	Plug	Diameter: 1/2 mile	Fine-grained, subequigranular (imperfect granophyric)	Occult in groundmass	Anorthoclase laths and anhedral xls.		
Agua Fria Mountain	Paisanitic riebeckite soda rhyolite	Deroofed intrusive	Diameter: 2 miles	Fine-grained, porphyritic (granophyric groundmass)	Interstitial	Anorthoclase phenocrysts and groundmass		Aegirite-augite
Hill 4142 (SE)	Soda (?) trachyte	Plug	Diameter: 1/4 mile	Fine-grained, porphyritic (imperfect trachytic)	Trace	Anorthoclase up to 1.7 x 0.8 mm. Alkali laths 0.13 x 0.05 mm.		
Red Bluff	Soda trachyte	Ruptured, partially deroofed trap-door intrusive	1 x 1/2 mile	Fine-grained, subequigranular (good trachytic)	Practically quartz free	Pronounced orientation of alkali feldspar laths (0.3± mm.)		Aegirite-augite (brigh green, 28 extinction)
Paint Mountain	Trachyte (vesicular)	Flows	Length: 1/4 mile Thickness: 30± feet	Very fine-grained, subequigranular (subtrachytic)		Abundant small laths (0.1 to 0.2 mm.)		Scattered augite grains
Hill 3600 (WC)	Plagioclase trachyte	Vertical dike	Length: 1 mile Width: few feet	Fine-grained, subequigranular	Little or none	Anorthoclase ($2V=50^{\circ}$) xls. average 0.35 mm.	Small % of armored and indistinctly zoned sodic plagioclase	
In draw 3/4 mile SW of Hill 3963 (SW)	Andesine trachyte	Flow (lower)	Length: 2± miles Thickness: 25± feet	Fine-grained, porphyritic		Abundant laths 0.2 x 0.05 mm.	Armored andesine (An36-46) pheno. up to 1+ mm.	Considerabl augite. One xl. 1 x 0.66 mm.
Dome just north of Hill 4142 (SE)	Trachy-andesite (?)	Sills	Diameter: 0.3 mile	Fine-grained, sparingly porphyritic	Little interstitial	Phenocrysts up to 2 mm. Groundmass laths and stubby xls.	Few andesine (An33) phenocrysts. Plagioclase groundmass laths.	
Hill 3251 (SC)	Trachy-andesite (?) (brecciated and badly weathered)	Plug-like intrusive	Diameter: 0.15 mile	Fine-grained, porphyritic (trachytic)	ANALCIME	Few anorthoclase (med. 2V) pheno. Alkali laths and stubby xls. (0.3 x 0.2 mm.) in groundmass.	Rare phenocrysts up to 0.8 mm. Clear groundmass laths (n > 1.54).	
South flank of Hill 3903 (SW)	Trachy-andesite (?) (vesicular)	Flow (lower)	Length: 2± miles Thickness: 25± feet	Very fine-grained, porphyritic (subtrachytic)		Stubby to lath-shaped groundmass xls. (n < 1.54) 0.15± mm.	Thin alkali armor on zoned andesine (An45) phenocrysts (up to 2 mm.)	Trace augite
3/4 mile N 30 E of Camels Hump	Altered analcime plagioclase micro-syenite (?)	Uncovered sill	0.2 x 0.1 mile	Fine-grained, porphyritic	Interstitial, rudimentary ocellar, and replacement types. Turbid.	Phenocrysts and long laths. (Probably originally more abundant).	Large labradorite (An56) phenocrysts up to 8 mm. Zoned and armored laths.	Augite inclusions in phen crysts. Pur augite xls.
South flank of Red Bluff	Altered analcime plagioclase syenite (?)	Sill	Length: 1+ mile	Medium-grained, porphyritic	As alteration product and replacement after feldspar	(Probably bulk of original feldspar was alkali)	Labradorite (An65) phenocrysts up to 2.5 mm. Armored laths.	Zoned, titani (purplish) au up to 2.5 mm hosts to apat ores.
South of Agua Fria Mountain	Altered analcime plagioclase micro-syenite (?)	Uncovered sill (?) or plug (?)	Diameter: 1/2 mile	Fine-grained, subequigranular	As deuteric product and cavity fill	Altered laths and subquadratic xls. more abundant than plagioclase	Altered laths show albite twinning	Microlites an crystallites o augite
Hill 3700 (SW)	Andesite	Dike	Length: 1 mile Width: few feet	Microporphyritic (subtrachytic)			Andesine (An35) laths, up to 0.3 mm., in feldspathic paste.	
Hill 3580 (SW)	Trachy-basalt	Plug	Diameter: 0.1 mile	Fine-grained, porphyritic		Anorthoclase phenocrysts, 0.7 x 0.6 mm., grid twinning. Alkali laths and stubby xls.	Alkali armored phenocrysts, zoned (An63 to An30), up to 2.2 x 1.3 mm. Seriate laths.	

TABLE 1– PETROGRAPHY OF THE IGNEOUS ROCKS OF THE AGUA FRIA QUADRANGLE, TEXAS

FELDSPAR		PYROXENES	AMPHIBOLES	OLIVINE, SERPENTINE, IDDINGSITE	ORES	APATITE
ALKALI	PLAGIOCLASE					
bundant laths and ubby xls. (0.1± mm.)					Altering to limonite	
۱% anorthoclase ienocrysts (3 x 1 m.) and ground- ass laths (0.2± mm.)			Hornblende (?) xls., 1.2 x 0.35 mm., altering to limonite		7% ores. Magnetite grains; limonite.	
ıorthoclase pheno- ysts (4± mm. long). kali laths 0.1± mm.		Trace aegirite-augite (?)	Little riebeckite (?)		Rare grains magnetite(?)	Few needles
ıorthoclase laths and ıhedral xls.			Small grains and few spongy riebeckite xls. up to 0.8 x 0.35 mm.		Rare magnetite grains up to 0.05 x 0.25 mm.	
northoclase pheno- ysts and groundmass		Aegirite-augite	Spongy riebeckite xls. and many scattered grains			
northoclase up to 7 x 0.8 mm. Alkali ths 0.13 x 0.05 mm.					Magnetite grains. Hematite and limonite.	
ronounced orientation alkali feldspar laths .3± mm.)		Aegirite-augite (bright green, 28° extinction)	Grains of rieb. and brownish sodic (?) hbl. Zoned xls. (0.35 x 0.15 mm.) of rieb. and arfved.(?)		Magnetite grains and skeleton xls. Limonitic material.	
›undant small laths .1 to 0.2 mm.)		Scattered augite grains			Few magnetite xls. (up to 0.7 mm.). Limonite from ore grains.	Minute stubby xls. associated with magnetite
ıorthoclase (2V=50°) s. average 0.35 mm.	Small % of armored and indistinctly zoned sodic plagioclase		Few hornblende grains		Small xls. and grains of magnetite and ilmenite (?)	Needles notably developed
ıundant laths ! x 0.05 mm.	Armored andesine (An36-46) pheno. up to 1+ mm.	Considerable augite. One xl. 1 x 0.66 mm.		Some serpentine from augite	Magnetite up to 0.7 mm. has alkali feldspar inclusions. Limonite.	Stubby xls. up to 0.5 x 0.2 mm.
enocrysts up to nm. Ground- ıss laths and ıbby xls.	Few andesine (An33) phenocrysts. Plagioclase groundmass laths.				Limonite patches, specks, and grains	Few xls. and many needles
w anorthoclase ed. 2V) pheno. kali laths and stubby . (0.3 x 0.2 mm.) in oundmass.	Rare phenocrysts up to 0.8 mm. Clear groundmass laths (n > 1.54).		BIOTITE			
bby to lath-shaped ıundmass xls. < 1.54) 0.15± mm.	Thin alkali armor on zoned andesine (An45) phenocrysts (up to 2 mm.)	Trace augite		Iddingsite ghosts up to 0.7 mm.	Magnetite xls. up to 0.5 mm.	In phenocrysts and magnetite. Up to 2 mm. in groundmass.
enocrysts and long hs. (Probably ginally more ındant).	Large labradorite (An56) phenocrysts up to 8 mm. Zoned and armored laths.	Augite inclusions in phenocrysts. Purplish augite xls.	Small inclusions in phenocrysts. Plentiful in groundmass. Alters to greenish material.	Serpentine and olivine ghost xls. Spherulitic serpentine.	Magnetite and pyrite grains, ilmenite; limonite, leucoxene	Large, fat, stubby xls.
obably bulk of ginal feldspar was ali)	Labradorite (An65) phenocrysts up to 2.5 mm. Armored laths.	Zoned, titaniferous (purplish) aug. xls., up to 2.5 mm., hosts to apatite and ores.	Long, thin, fresh shreds	Iddingsite and limonite ghosts, up to 2+ mm., after ol. (?). Serp. in groundmass.	Magnetite, pyrite, ilmenite; leucoxene	Small xls.
›red laths and sub- dratic xls. more ıdant than ioclase	Altered laths show albite twinning	Microlites and crystallites of augite		Much light green serpentine material in groundmass	Magnetite grains and xls.	Small xls.
	Andesine (An35) laths, up to 0.3 mm., in feldspathic paste.				Magnetite xls. up to 0.2 mm. Limonite.	
›thoclase pheno- ts, 0.7 x 0.6 mm., twinning. Alkali ; and stubby xls.	Alkali armored phenocrysts, zoned (An63 to An30), up to 2.2 x 1.3 mm. Seriate laths.				Magnetite grains and xls., ilmenite; limonite, leucoxene	Few small xls.

'INE, NTINE, GSITE	ORES	APATITE	OTHER MINERALS	REMARKS
	Altering to limonite		Trace zircon (?)	Reddish-brown alteration material from riebeckite (?). Xls. set in feldspathic paste.
	7% ores. Magnetite grains; limonite.		Few zircon grains	Mode modified from Lonsdale (1940, p. 1567). Reddish-brown alteration material from amphibole(?) and/or pyroxene (?).
	Rare grains magnetite(?)	Few needles	Trace zircon. Titanite (?).	Apparent zoning in a few feldspar phenocrysts.
	Rare magnetite grains up to 0.05 x 0.25 mm.		Few zircon xls.	Riebeckite pleochroic from dark blue-green to yellow-green, alters rusty brown.
				Spongy riebeckite xls. poikilitic to anorthoclase and quartz. Riebeckite alters reddish-brown, strongly pleochroic, 5° to 7° extinction.
	Magnetite grains. Hematite and limonite.		Greenish microlites	Reddish-brown material altered riebeckite (?).
	Magnetite grains and skeleton xls. Limonitic material.			Sodic amphiboles markedly pleochroic, xl. ends fibrous and dark blue-green to black, maximum extinction 12°, fairly high relief.
	Few magnetite xls. (up to 0.7 mm.). Limonite from ore grains.	Minute stubby xls. associated with magnetite		Reddish-brown material suggests soda rich mafics. Possibly a soda trachyte. Two flows.
	Small xls. and grains of magnetite and ilmenite (?)	Needles notably developed		Numerous small vesicles. Few filled with calcite; few partially filled with clear to slightly clouded isotropic material.
pentine te	Magnetite up to 0.7 mm. has alkali feldspar inclusions. Limonite.	Stubby xls. up to 0.5 x 0.2 mm.		1± mm. ghosts of serpentine, calcite, and limonite. Alteration of plagioclase cores provides additional greenish material.
	Limonite patches, specks, and grains	Few xls. and many needles	Little leucoxene	Calcite: secondary and as alteration of feldspar. Rock badly weathered, possibly andesine trachyte.
			Calcite veins and cavity fill	Rock composed principally of feldspar. Some phenocrysts have glassy armor.
ghosts nm.	Magnetite xls. up to 0.5 mm.	In phenocrysts and magnetite. Up to 2 mm. in groundmass.	Opal and tridymite amygdules	Pasty groundmass with feldspar laths, minute specks, needles, rods, and light yellow-green alteration material.
e and ost xls. c e.	Magnetite and pyrite grains, ilmenite; limonite, leucoxene	Large, fat, stubby xls.		Highly analcitized rock. Suggests originally more potash feldspar. Greenish alteration material has peculiar reddish pleochroic color characteristic of sodic rocks.
and hosts, up , after erp. in ss.	Magnetite, pyrite, ilmenite; leucoxene	Small xls.	Spherulitic to fibrous zeolites	Deuteric alteration extensive. Practically indeterminate. Calcite in cavities.
t green e material nass	Magnetite grains and xls.	Small xls.	Little fibrous zeolite	Seriate xls. Deuteric action; rock appears fresh, but practically indeterminate. Calcite in cavities and alteration product.
	Magnetite xls. up to 0.2 mm. Limonite.		Minute perovskite (?) grains	Light colored pasty groundmass with iron ore specks and minute plagioclase needles. Calcite abundant (xls. up to 0.3 mm.).
	Magnetite grains and xls., ilmenite; limonite, leucoxene	Few small xls.	Calcite from calcic feldspar and in vesicles	Microperthitic. Excellently zoned and armored feldspar.

TABLE 1–PETROGRAPHY OF THE IGNEC

LOCALITY	ROCK	OCCURRENCE	DIMENSIONS	TEXTURE	ANALCIME	FELDSPAR		PYRO›
						ALKALI	PLAGIOCLASE	
Dome just north of Hill 4142 (SE)	Analcime trachybasalt porphyry (badly weathered)	Sill	Diameter: 0.3 mile	Fine-grained, porphyritic	As cavity fillings and replacement type	Xls., armor, and in groundmass	Zoned and armored An64 phenocrysts up to 3.5 mm. Groundmass laths.	
North Pitahaya Hill	Analcimitic trachy-dolerite	Uncovered sill	Numerous small isolated exposures	Fine- to medium-grained, seriate (ophitic)	Little primary and interstitial	Considerable amount	Labradorite	Purplish xls. up tc mm.
Hill 3604 (SE)	Analcime trachybasalt porphyry	Uncovered sill	1 x 0.5 mile	Fine-grained, porphyritic	Turbid to clear interstitial, replacement, and cavity fill	Few phenocrysts and as groundmass xls.	Zoned and armored An60 phenocrysts up to 7 mm. Plagioclase laths in groundmass.	Purplish xls. Sorr hour glas structure
Hill 3683 (SE)	Analcime syeno-gabbro (?) porphyry	Uncovered sill	1.5 x 0.5 mile	Fine- to medium-grained, porphyritic	Cloudy to clear interstitial and replacement	Relatively high % anorthoclase. Alkali groundmass laths average 0.3 mm.	Zoned and armored lab. pheno. av. 1 x 1.5 mm. and partly replaced by analcime. Plag. laths average 0.3 mm.	Gray to p subhedra augite xl
Terlingua Creek 0.3 mile west of Panther Mountain	Analcime micro-syenogabbro (?) (badly altered)	Sill	Exposed in canyon wall for 1/4 mile. Up to 50 feet thick.	Fine- to medium-grained, subequigranular	Clear to turbid interstitial patches up to 1.3 mm.	Perhaps equal in % to plagioclase	Armored An60 xls. up to 1.5 mm. Bundles of smaller laths.	Titanifer augite
1-1/2 miles due north of Pack-saddle Mountain	Analcime trachy-basalt (?) porphyry	Uncovered sill	Diameter: 0.1 mile	Fine-grained, porphyritic	Turbid. Interstitial, replacement, ocellar.	Groundmass laths. Stubby xls. Armor on plagioclase.	Zoned and armored labradorite phenocrysts up to 8 mm. Alkali rims on plagioclase laths.	Purplish, twinned a xls. up to mm. Sma in ground
Black Hill	Analcime basalt porphyry	Sills	Diameter: 0.15 mile	Fine-grained, porphyritic	Interstitial, replacement, and vesicle fill.	Few groundmass laths.	Zoned and armored An62 pheno., up to 4.5 mm., poikilitic to augite, magnetite, and olivine. Plag. groundmass laths.	Augite gr and small
Hill 3550 (SE)	Analcime basalt	Uncovered sill	0.5 x 0.1 mile	Fine-grained, subequigranular (trachytic and ophitic)	Clear, primary, interstitial	Few xls. up to 0.5 x 0.4 mm.	Abundant laths, zoned An53 to An40	Augite xls to plagiocl
Fizzle Flat	Chilled basalt	Dike	Length: 2.2 miles Width: 10 to 12 feet	Exceedingly fine-grained with few plagioclase xls. (subtrachytic)		Slight alkali armor on plagioclase	Seriate zoned and armored An65 laths up to 1.5 mm. Poikilitic to olivine and magnetite grains.	Minute aug grains
Hill 3494 (SC)	Analcimitic diabasic microgabbro	Flow (?)	Diameter: 0.2 mile Thickness: 20 ± feet	Fine- to medium-grained, seriate (ophitic)	Little interstitial and as alteration of plagioclase	Little as rims and crude perthitic intergrowth	Slightly zoned and armored An63 to An55 xls., up to 1.2 mm., with minute inclusions. Slender laths (0.2 ± mm.).	Faint purp augite xls. 1.8 mm.
South flank of Hill 3903 (SW)	Analcimitic diabasic microgabbro	Flow (upper)	Length: 2 ± miles Thickness: 25 ± feet	Fine- to medium-grained, subequigranular (ophitic)		Very little	Lath shaped An67 xls. up to 2 mm. Abundant plagioclase laths.	Aug. grain xls., up to hosts to la iddingsite
Black ridge 1-1/2 miles SW of Agua Fria Mt.	Analcime basalt porphyry	Uncovered sill	1/2 x 1/2 mile within quadrangle (extends beyond map)	Fine-grained, porphyritic	Interstitial	Little as thin armor on large plagioclase phenocrysts	Very large, clear, An60 phenocrysts. Plagioclase groundmass laths, 0.3 to 0.4 mm.	Small augit xls.
Hill 3580 (SW)	Olivine basalt porphyry	Dike	Length: 0.1 mile Width: 1 to 2 feet	Fine-grained, porphyritic		Little as rim on plagioclase feldspar	Slightly zoned and thinly armored An60 phenocrysts, up to 2 mm., poikilitic to magnetite, olivine, and augite grains. Seriate plagioclase laths.	Small augit xls. and microlites
Black Hill 1 mile SW of Pack-saddle Mt.	Picritic basalt	Plug	Diameter: 0.2 mile	Fine- to medium-grained, seriate	Trace (?)	Practically none	Minute An64 laths in paste	Abundant gr zoned augite up to 1.5 mr
Terlingua Creek 0.3 mile west of Panther Mountain	Analcime alkali basalt	Sill (upper)	Length: 1/4 + mile Thickness: 15 to 20 feet	Fine- to medium-grained, seriate	Clouded, plentiful in groundmass	Possibly little originally present in groundmass, but highly altered	Very small (labradorite?) laths, up to 0.5 mm.	Abundant zo twinned, and glass euhedr augite xls. u 1 mm.

?HY OF THE IGNEOUS ROCKS OF THE AGUA FRIA QUADRANGLE, TEXAS (CONT'D)

AGIOCLASE	PYROXENES	BIOTITE	OLIVINE, SERPENTINE, IDDINGSITE	ORES	APATITE	OTHER MINERALS	
d armored An64 sts up to 3.5 mm. ass laths.		Minute inclusions in plagioclase	Antigorite (?) after olivine (?). Serpentine material in groundmass.	Magnetite grains, rare ilmenite; limonite, leucoxene	Fat, stubby xls. in clots with altered mafics	Calcite after more calcic plagioclase	Ser pro
ite	Purplish augite xls. up to 1.5 mm.		Olivine xls., up to 1 mm., hosts to feldspar laths	Magnetite grains and xls.	Few xls.		Ser
i armored An60 sts up to 7 mm. se laths in iss.	Purplish augite xls. Some with hour glass structure.	Flakes	Serpentine-olivine xls. up to 2 mm. Serpentine in groundmass.	Magnetite grains. Ilmenite-leucoxene, up to 0.5 mm.	Xls. up to 1 mm. long	Sperulitic zeolites as alteration of feldspar	Stri ave
i armored lab. . 1 x 1.5 mm. r replaced by . Plag. laths).3 mm.	Gray to purplish subhedral augite xls.	Rare flakes	Serpentine from olivine	Magnetite grains and small xls. Trace pyrite.	Numerous needles	Chlorite. Little calcite.	Clu and
An60 xls. up to Bundles of aths.	Titaniferous augite	Rare flakes	Serpentine ghosts after olivine. Serpentine (?) in groundmass.	Pyrite and magnetite grains and small xls.	Needles and small xls.	Sperulitic zeolites	Muc ser clas
l armored .e phenocrysts n. Alkali rims lase laths.	Purplish, twinned augite xls. up to 2 mm. Small xls. in groundmass.	Flakes outline analcime ocelli	Serpentine-olivine xls., up to 1.7 mm., hosts to apatite. Serp. in groundmass	Magnetite and pyrite. Ilmenite-leucoxene.	Fat, stubby xls. and irregular shapes	Fibrous zeolites. Little calcite.	Hig thar alte rim
armored An62 to 4.5 mm., :o augite, mag- l olivine. Plag. ss laths.	Augite grains and small xls.		Olivine xls., up to 1.3 mm., serpentine along cracks. Both in groundmass.	Magnetite grains and small xls.	Small elongate xls.	Fibrous to spherulitic zeolites	Pla aug Am zeo
aths, zoned 140	Augite xls., hosts to plagioclase		Olivine (0.5 to 1 mm.)	Magnetite grains and xls. up to 0.7 mm.		Calcite as cavity material	Ser lath
ned and armored up to 1.5 mm. :o olivine and grains.	Minute augite grains		Olivine grains and xls. up to 0.6 mm.	Unusually abundant minute magnetite grains			Sup min mag han
ned and An63 to An55 1.2 mm., with lusions. Slender : mm.).	Faint purplish augite xls. up to 1.8 mm.	Small wisps	Numerous small slightly serpentinized olivine xls.	Magnetite grains, xls., and small inclusions in feldspar			Son
d An67 xls. . Abundant laths.	Aug. grains and xls., up to 2 mm., hosts to lab. and iddingsite		Olivine xls., up to 2 mm., alter to iddingsite	Small grains and rods of magnetite (?)		Calcite fills vesicles and cracks	Thi bad
clear, An60 s. Plagioclase s laths, 0.3 to	Small augite xls.		Slightly serpentinized olivine grains and xls. up to 0.8 mm. Also in groundmass.	Magnetite grains			Ser lab Chi
ed and thinly 160 pheno- o 2 mm., magnetite, augite grains. ioclase laths.	Small augite xls. and microlites (?)	Rare minute flakes	Euhedral olivine xls., up to 0.8 mm., serpentine along cracks. Olivine in groundmass.	Magnetite grains			Pas plag Ser Chi
l laths in	Abundant gray, zoned augite xls. up to 1.5 mm.	Few wisps	Abundant olivine up to 1.5 mm. with serpentine along cracks	Scattered magnetite grains	Trace		Pas See for
(labradorite?)).5 mm.	Abundant zoned, twinned, and hour glass euhedral augite xls. up to 1 mm.	Flakes up to 0.5 mm. long	Abundant serpentine-olivine xls. up to 1.5 mm. long	Magnetite grains	Present	Fibrous and spherulitic zeolites	Low mas lab affi calc

VINE, ENTINE, NGSITE	ORES	APATITE	OTHER MINERALS	REMARKS
e (?) after ?). Serpen- erial in ass.	Magnetite grains, rare ilmenite; limonite, leucoxene	Fat, stubby xls. in clots with altered mafics	Calcite after more calcic plagioclase	Serpentine, calcite, and analcime as alteration products.
ls., up to osts to laths	Magnetite grains and xls.	Few xls.		Seriate grain size. Specimen fresh.
ie-olivine 2 mm. ie in ass.	Magnetite grains. Ilmenite-leucoxene, up to 0.5 mm.	Xls. up to 1 mm. long	Sperulitic zeolites as alteration of feldspar	Strikingly porphyritic. Groundmass xls. average 0.1 to 0.2 mm.
ie from	Magnetite grains and small xls. Trace pyrite.	Numerous needles	Chlorite. Little calcite.	Clusters of serpentine, olivine, magnetite, and augite.
ie ghosts rine. ie (?) in ass.	Pyrite and magnetite grains and small xls.	Needles and small xls.	Sperulitic zeolites	Much deuteric alteration of minerals to serpentine, analcime, and zeolites. Exact classification indeterminate.
ie-olivine o 1.7 mm., apatite. groundmass	Magnetite and pyrite. Ilmenite-leucoxene.	Fat, stubby xls. and irregular shapes	Fibrous zeolites. Little calcite.	Highly altered. Probably more plagioclase than alkali feldspar. Some completely altered plagioclase cores have fresh alkali rims.
ls., up to serpen- g cracks. roundmass.	Magnetite grains and small xls.	Small elongate xls.	Fibrous to spheru- litic zeolites	Plagioclase rich rock. Clots of fine-grained augite and ore grains in feldspathic paste. Amygdules of calcite, analcime, and zeolites.
0.5 to	Magnetite grains and xls. up to 0.7 mm.		Calcite as cavity material	Seriate mafics show lineation. Plagioclase laths in bundles. Fresh specimen.
rains and 0.6 mm.	Unusually abundant minute magnetite grains			Super chilled rock. Feldspathic paste with minute laths and grains of plagioclase, magnetite, olivine, and augite. Aphanitic hand specimen.
s small erpen- ivine xls.	Magnetite grains, xls., and small inclusions in feldspar			Some alignment of feldspar laths.
ls., up to lter to e	Small grains and rods of magnetite (?)		Calcite fills vesicles and cracks	Thin section fresh; hand specimen appears badly weathered.
erpentin- ne grains up to 0.8 o in ass.	Magnetite grains			Seriate grain size in groundmass. Clear labradorite phenocrysts, 2± inches long. Chilled rock.
olivine o 0.8 mm., ie along Olivine lmass.	Magnetite grains			Pasty groundmass with laths and stubby plagioclase, minute ore and olivine grains. Seriate iron rich olivine is biaxial negative. Chilled rock.
olivine mm. with ie along	Scattered magnetite grains	Trace		Pasty groundmass. Rock is feldspar poor. See Lonsdale (1940, No. XX of Table 17) for chemical analysis.
serpen- ne xls. mm. long	Magnetite grains	Present	Fibrous and spherulitic zeolites	Low % clouded, pasty, feldspathic ground- mass; zeolitized feldspar probably labradorite; biotite indicates alkaline affinity of mafic rich rock; secondary calcite.

to the northeast structural trends of the subsurface Paleozoic rocks.

Normal Faults

Both folding and faulting are widespread in the Big Bend sunken block, but normal faults are the most important structural element in the Agua Fria quadrangle. Even in domical uplifts, such as Packsaddle Mountain, and in trap-doors, such as Gray Hill, faulting rather than simple folding chiefly governs the resulting structure (Fig. 3). Many faults in the area occur in pairs, and two faults may extend parallel for miles. More of the narrow intervening fault blocks are grabens than horsts, and rift valleys are not uncommon. Notable grabens are the rift valley in the Boquillas in the extreme northeast corner of the quadrangle and the block composed of Gulf Cretaceous and Tertiary strata of which Paint Mountain is a part.

The trend of the major faults is northwesterly except in the southern part of the quadrangle, where the strike of Tascotal Mesa fault, for example, changes from northwest to due west. This decided change indicates that Panther Mountain, Agua Fria Mountain, and the Solitario have influenced structural conditions tremendously in this part of the quadrangle.

The throw of most of the major faults amounts to hundreds of feet, and the trace of many is marked by a prominent fault scarp (Table 2). From northeast to southwest, with few exceptions, the northwest-trending faults are progressively downthrown to the southwest.

Cheosa Waterhole fault is, more specifically, a fault zone; the faulting, especially northwest of Terlingua Creek, consists of numerous relatively short echelon faults that cut the rocks into slivers. This fault zone, like many other faults of the area, dies out to the northwest.

The normal faults that bound the Riddle Ridge (C) horst on the northeast and southwest are practically vertical, and apparently the same two faults continue in a northwesterly direction under a gravel cover (Pl. 1). If so, the faults are pivotal, for the vertical movement northwest of the supposed axis of rotation (position concealed by gravel) is in the opposite direction to that southeast of it. Thus the block that is a horst at its narrow southeast end widens and develops into a graben to the northwest.

Hill 3564, southwest of Packsaddle Mountain, is a significant horst, because the telescopic structural effect described in the discussion of Agua Fria Mountain is well developed in the Boquillas flags in this hill. Perhaps an uncovered igneous intrusive is responsible for this type of structure, in which a concentric fault pattern develops with beds nearer the structural center of the hill pushed progressively higher than those nearer the periphery.

TABLE 2.—ESTIMATED STRATIGRAPHIC THROW OF SEVERAL MAJOR FAULTS

Fault	Position	Approximate throw in feet
Old Stage Stand	Old Stage Stand	500
Hale Cabin	Alpine-Terlingua road	500
Cheosa Waterhole	Alpine-Terlingua road	800
Fizzle Flat	Clanton-Agua Fria ranch road	500
Tascotal Mesa	Paint Mountain	1000±
Solitario	Hill 3903	2200±

Many of the faults at Packsaddle Mountain and Agua Fria Mountain are at right angles to the general northwesterly structural trend of the area. These local faults, several of which are radial, probably resulted directly from the intrusions. A narrow fault block of Aguja sandstone fringes the west escarpment of Agua Fria Mountain, and a small block of Boquillas limestone on the north side of the mountain has also been elevated by the intrusion.

AGE OF THE FAULTING: Most faulting in the Agua Fria quadrangle occurred in Tertiary time, possibly fairly late, because the Buck Hill volcanic series is involved. The local radial faults associated with plug and stock-like masses probably originated at the time the Tertiary igneous rocks were intruded. Tascotal Mesa fault probably is younger than or contemporaneous with the Agua Fria intrusion, because that igneous mass definitely controls the fault pattern of the area surrounding it.

Part of the fault pattern in the Agua Fria quadrangle may have been established during the Laramide revolution at the close of Cretaceous time, so that renewed movements occurred along the existing fault zones during Tertiary time. Evidence for this conclusion is found at Hill B.M. 3540 and Hill 3546 in the central part of the quadrangle, less than 1½ miles apart. Hill B.M. 3540 lies slightly northeast of the Cheosa Waterhole fault zone, and Hill 3546 is within the zone. Both hills are capped by seemingly correlative Tertiary limestones. That at Hill B.M. 3540 rests on beds of the Fizzle Flat lentil, but between the base of the limestone at Hill 3546 and the top of the Fizzle Flat lentil are 83 feet of tuffaceous material, 16 feet of basal Tertiary conglomerate, and 57 feet of medium gray Terlingua (?) beds. At least 156 feet more section is preserved under the limestone on the downthrown side of the fault than on the upthrown. This suggests that Hill B.M. 3540 either stood so high that the members of the Buck Hill volcanic series older than the limestone cap were never deposited on it, or else they were deposited and subsequently eroded so that the fresh-water limestone was deposited on the Fizzle Flat lentil. In either event, sufficient displacement had already taken place prior to the deposition of the Tertiary limestone to preserve an additional 156 feet of sediments on the downthrown side of the fault. Perhaps at this particular place the faulting was a slow but continuous process that lasted from Laramide time to post-fresh-water limestone time, because the Tertiary limestone at Hill 3546 has been folded and distorted by faulting, even though it still maintains essentially the same elevation as the limestone at Hill B.M. 3540.

Domes

Folding is expressed appreciably in the quadrangle only in highly faulted domes. The best trap-door dome is Gray Hill. Other possible trap-doors or domes similar to them include Red Bluff and Panther Mountain. The Solitario and the small patch of Boquillas flags just east of the Alpine-Terlingua road at the south boundary of the area are typical domes. Hill 3564 southwest of Packsaddle Mountain is a dome-like uplift with a ground plan the shape of a flat-iron and with concentric faults that operated in a telescopic manner. Half Dome (SC) and the area just west of north Pitahaya Hill are domes that have been cut in half by faulting. Fizzle Flat and the area northeast of the intersection of Hale Cabin fault and the Alpine-Terlingua road might be included in a similar category. These very broad upwarps, the axes of which plunge gently to the northeast and are at right angles to the faults, form very broad half-dome structural features. A test well for oil drilled at the crest (just east of the road) of the gently arched upthrown fault block northeast of the Hale Cabin fault was dry and abandoned.

GEOLOGIC HISTORY

Late in Paleozoic time, the dominantly clastic sediments of the Marathon geosyncline were buckled, folded, and overthrust to the northwest. This diastrophism established the prevailing northeast trends in the Marathon and Solitario areas and obliterated the Paleozoic geosyncline. From late Paleozoic to early Cretaceous time the area stood above sea level and was eroded. Exposures in a deep and narrow canyon on the east flank of the Solitario reveal that, when the earliest Cretaceous seas advanced into the area, the Trinity sandstone and conglomerate were deposited on the beveled edges of highly inclined Paleozoic strata. Then, in sequence, follow several hundred feet of Glen Rose limestone, a few tens of feet of Maxon sandstone, several hundred feet of Devils River limestone, the Grayson, Buda, and Boquillas.

All Cretaceous sedimentary rocks within the quadrangle, with the possible exception of a small amount of Aguja, are marine. Adkins (1933, p. 505–508) points out that some of the upper Aguja beds are nonmarine, but few, if any, of the younger Aguja beds are preserved in the area. If the Tornillo clay, which is well developed farther south, was ever deposited in the Agua Fria quadrangle, it was removed by erosion during and following the Laramide revolution.

Most of the faulting occurred after the deposition of the Buck Hill volcanic series, for these strata are cut by faults. If a fault system developed in late Cretaceous time, presumably the late Tertiary faulting recurred along these older lines of weakness. The angular unconformity which separates the basal Tertiary conglomerate from the east-dipping Comanche and Gulf Cretaceous formations on the northeast flank of the Solitario indicates that this structure, although not in its present form, became a positive element during the Laramide revolution.

Because the Santiago Mountains to the northeast also originated during the Laramide revolution, the Agua Fria area has probably been structurally negative since the close of Cretaceous time.

The erosion that resulted from the regional Laramide uplift removed all strata down to the Fizzle Flat lentil in the northern part of the Agua Fria quadrangle, but the section up through the lower Aguja beds is preserved in the south. Therefore, the basal Tertiary conglomerate, because of the widespread angular unconformity, rests on the beveled edges of progressively younger Cretaceous strata from north to south within the quadrangle. In the adjoining Buck Hill quadrangle to the north, the conglomerate rests on the Boquillas flags; and, according to Goldich and Elms (1949, p. 1173): "The persistence of the basal Tertiary conglomerate suggests that a similar break might be expected between the Tornillo formation, if it is of Cretaceous age, and the Chisos beds in the Chisos Mountains area." Apparently Udden's sunken block has exerted a dominant regional influence on erosion, deposition, and preservation of strata in the Big Bend area during Tertiary time.

The basal conglomerate of the Pruett consists principally of well-rounded pebbles and cobbles of Comanche limestones. Chert is also a constituent, and more angular materials were derived locally from underlying Cretaceous formations. The lack of igneous pebbles and cobbles in the conglomerate suggests either that igneous activity in the area had not commenced at the time the conglomerate was laid down or that the igneous rocks had not yet been exposed to erosion. The appearance of igneous pebbles and cobbles in younger breccias and conglomerates of the Buck Hill volcanic series indicate that an igneous source was supplying materials by the time these beds were deposited.

Goldich and Elms (1949, p. 1173–1175) have presented a detailed account of the history of the Buck Hill volcanic series which applies also to the Agua Fria quadrangle. The following points have been abstracted from that reference.

(1) Several widely spaced localities exhibit the regional angular unconformity between Cretaceous strata and the Tertiary volcanics.

(2) The Pruett is tentatively assigned to the Eocene on the basis of fossil gastropods in the fresh-water limestones, and the Duff formation is tentatively assigned to the Oligocene.

(3) Tertiary deposition probably was not continuous; undoubtedly materials were reworked and locally removed by streams. Breaks in the tuffs can escape detection because of the nature of the materials.

(4) Stratification of the tuffs and fresh-water limestones indicate that much of the Pruett was probably deposited in large temporary and shallow lakes.

(5) The high $CaCO_3$ content of the lower part of the Pruett suggests a mechanical derivation from exposed Cretaceous rocks, but some of the thick limestone sequences were precipitated. Algal structures and charophytes suggest an organic origin for much of the limestone.

(6) The source of the volcanic ash is problematical. The finer material could have come from great distances, but the breccia-conglomerates probably were derived from near-by sources.

(7) The intrusions, although all may not be of the same age, antedate the late faulting and indicate activity in late Tertiary time. In the southwestern part of the Jordan Gap quadrangle, igneous plugs intruded the younger Tascotal tuff beds. (Perhaps it was also at this time that a laccolithic intrusion raised the Solitario dome like a huge blister, which became the crest of the more extensive Solitario uplift.)

(8) The time of folding and faulting of the Buck Hill volcanic series is at least late Tertiary and is older than the basin fill and alluvial deposits of the region.

(9) Since the late Tertiary uplift, erosion has removed a great thickness of the volcanic series, forming Green Valley and again exposing the Cretaceous strata. Terraces (west of Terlingua Creek near Clanton ranch) and alluvial deposits indicate that the process has been

controlled by temporary base levels, and the present active downcutting indicates recent rejuvenation.

ECONOMIC GEOLOGY

Several structures that would make excellent oil traps are present in the Agua Fria quadrangle, but all tests for petroleum in the area have been unsuccessful. The Tertiary igneous rocks have intruded the sediments which would be the potential reservoir rocks, thereby decreasing porosity and permeability in some cases. Thermal effects would tend to destroy any hydrocarbons that may have been present when the domes were formed.

Copper prospects in the Solitario are reported by Baker (1935b, p. 412), and traces of native copper were found in the Boquillas flags on the northeast flank of the Solitario. But copper in commercial quantities probably does not occur in the Agua Fria quadrangle.

The same can be said of hematite, a few loose specimens of which were found on the northeast flank of Packsaddle Mountain. These are probably erosional remnants from the Aguja sandstone.

In this semidesert country which is devoted exclusively to ranching, water is by far the most important economic mineral. Agua Fria Spring, the most dependable and best supply of water in the quadrangle, is literally an oasis in the desert. Its output, apparently dependent upon the amount of rainfall received during the preceding year, fluctuates somewhat from year to year, but the spring has never run dry. There are several permanent water-holes and short stretches along Terlingua Creek, the greater extent of which is intermittent, and relatively shallow water wells dug near the creek are usually successful. Water in the northeast portion of the quadrangle is very scarce and must be pumped there through pipe-lines from Terlingua Creek and other sources. The area as a whole relies for its water for stock on surface run-off that collects in earthen tanks during and after cloudbursts, which are fairly common during the summer months.

Mansfield and Boardman (1932, p. 55–57) reported a nitrate deposit "without commercial possibilities" at Agua Fria Spring. The minerals from the deposit were described by Lonsdale (1926) as niter and soda niter.

REFERENCES CITED

Adkins, W. S. (1933) *The Mesozoic systems in Texas,* Pt. 2, *The geology of Texas,* vol. I, *Stratigraphy,* Univ. Texas, Bull. 3232, p. 239–518.

Baker, C. L. (1935a) *Major structural features of Trans-Pecos Texas,* Pt. 2, *The geology of Texas,* vol. II, *Structural and economic geology,* Univ. Texas, Bull. 3401, p. 137–214.

——*et al.* (1935b) *Economic geology of Texas,* Pt. 3, *The geology of Texas,* vol. II, *Structural and economic geology,* Univ. Texas, Bull. 3401, p. 215–884.

Cragin, F. W. (1894) *The Choctaw and Grayson terranes of the Arietina* [Texas], Colo. College Studies, vol. 5, p. 40–48.

Eifler, G. K., Jr. (1943) *Geology of the Santiago Peak quadrangle, Texas,* Geol. Soc. Am., Bull., vol. 54, p. 1613–1644.

Fenner, C. N. (1948) *Incandescent tuff flows in southern Peru,* Geol. Soc. Am., Bull., vol. 59, p. 879–893.

Goldich, S. S., and Elms, M. A. (1949) *Stratigraphy and petrology of the Buck Hill quadrangle, Texas,* Geol. Soc. Am., Bull. vol. 60, p. 1133–1182.

—— and Seward, C. L. (1948) *Green Valley-Paradise Valley field trip,* West Texas Geol. Soc. guide-book, p. 10–36.

Hatch, F. H., and Wells, A. K. (1937) *The petrology of the igneous rocks,* 9th ed., George Allen & Unwin Ltd., London, 368 pages.

Henderson, Junius (1935) *Fossil non-marine Mollusca of North America,* Geol. Soc. Am., Spec. Paper 3, 313 pages.

Hill, R. T. (1900) *Physical geography of the Texas region,* U. S. Geol. Survey, Topog. Atlas, Folio 3, p. 1–12.

—— and Vaughan, T. W. (1898) *Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas,* U. S. Geol. Survey, Ann. Rept. 18, pt. 2, 193–321.

Huffington, R. M. (1943) *Geology of the Northern Quitman Mountains, Trans-Pecos Texas,* Geol Soc. Am., Bull, vol. 54, p. 987–1046.

Knechtel, M. M. (1944) *Oil and gas possibilities of the plains adjacent to the Little Rocky Mountains, Montana,* U. S. Geol. Survey, Oil and Gas Invest., Prelim. Map 4.

Lonsdale, J. T. (1926) *Niter and soda niter from Brewster County, Texas,* Am. Mineral., vol. 11, p. 189–190.

—— (1940) *Igneous rocks of the Terlingua-Solitario region, Texas,* Geol. Soc. Am., Bull., vol. 51, p. 1539–1626.

—— and Dickson, K. O. (1948) *Analcime suite of igneous rocks, Brewster County, Texas* (Abstract), Geol. Soc. Am., Bull., vol. 59, p. 1337.

Mansfield, G. R., and Boardman, Leona (1932) *Nitrate deposits of the United States,* U. S. Geol. Survey, Bull 838, 107 p.

—— and Ross. C. S. (1935) *Welded rhyolitic tuffs* *in southeastern Idaho,* Am. Geophys. Union, Tr., p. 308–321.

Niggli, P. (1931) *Die quantitative mineralogische klassification der eruptivgesteine,* Schweiz. Min. Pet. Mitt., Bd. XI, Heft 2, p. 296–364.

Scott, G. (1926) *Etudes stratigraphiques et paleontologiques sur les terrains cretaces du Texas,* Universite de Grenoble, Dr. Nat. Sci. Thesis.

Stephenson, L. W. (1948) *Notes on the stratigraphy of the Upper Cretaceous formations of the Big Bend area, Texas,* Bur. Econ. Geol., Univ. Texas, Unpublished.

Udden, J. A. (1907a) *Report on a geological survey of the lands belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande embayment in Texas,* Augustana Lib. Pub., no. 6, p. 51–107.

Udden, J. A. (1907b) *A sketch of the geology of the Chisos country, Brewster County, Texas,* Univ. Texas, Bull. 93, 101 p.

Vaughan, T. W. (1900) *Reconnaissance in the Rio Grande coal fields of Texas,* U. S. Geol. Survey, Bull. 164, p. 1–88.

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