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Stratigraphy and Petrology of Buck Hill Quadrangle, Texas

By

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ABSTRACT

Tertiary tuff beds and related sediments with intercalated lava flows, aggregating over 2000 feet, are named the Buck Hill volcanic series for outcrops in the Buck Hill quadrangle, Brewster County, Texas. The volcanic series rests unconformably on the Upper Cretaceous Boquillas formation. The Lower Cretaceous is represented by the Georgetown limestone, the Grayson clay, and the Buda limestone.

The lower 900–1000 feet of the Buck Hill volcanic series is named the Pruett formation, and the upper 1000–1400 feet, the Duff tuff. Lava flows up to 325 feet thick, designated the Cottonwood Spring basalt, separate these formations. A limestone pebble conglomerate and arkosic sandstone at the base of the Pruett mark the Cretaceous-Tertiary unconformity. The Pruett tuff commonly is calcareous and grades to beds of fossiliferous fresh-water limestone. A massive layer of breccia-conglomerate occurs near the top of the formation, approximately 60 feet below the base of the Cottonwood Spring basalt. Lava flows intercalated with the Pruett sediments, from oldest to youngest, are the Crossen trachyte, the Sheep Canyon basalt, and the Potato Hill andesite. The Duff formation is chiefly silicic tuff with minor breccia and a few thick beds of stream conglomerate. It is overlain by the Mitchell Mesa rhyolite, the youngest rock of the volcanic series in the quadrangle.

In the southern part of the quadrangle Straddlebug Mountain and Buck Hill are small intrusives of syenite; similar syenitic intrusives cut the Cretaceous, the Pruett tuff, and the Sheep Canyon basalt in the Elephant Mountain area. The igneous rocks are alkalic and chemically resemble the analyzed rocks from the Terlingua-Solitario region to the south.

The main structural features are west- and northwest-trending normal faults. Two major fault zones divide the quadrangle into three blocks with a middle down-dropped segment. Differential hardness of the rocks of the Buck Hill volcanic series controls the topography.

INTRODUCTION

Location

The Buck Hill quadrangle, west-central Brewster County, Trans-Pecos Texas, is on the southern front of the Davis Mountains (Figs. 1, 2). It is reached most easily from Alpine, 30 miles north, by the highway to Terlingua which traverses the quadrangle from north to south. Alternate routes are from Marathon by way of Del Norte Gap in the Del Norte-Santiago Mountain range and from Marfa by the 02 ranch road in Paradise Valley.

Previous Work

The older literature, including the pioneer work of Von Streeruwitz (1890), Vaughan (1900), Udden (1904; 1907b), and others, is reviewed in *The geology of Texas* (Plummer, 1932; Baker, 1934). The first petrographic work on the volcanic rocks of the Davis Mountains was by Osann (1892) on specimens collected by Von Streeruwitz. Lord (1900) made petrographic examinations of specimens collected by Vaughan in the Tierra Vieja Mountains. Much of the geologic knowledge of Trans-Pecos Texas is based on the extensive field work of C. L. Baker (1927; 1928; 1934; 1941; Baker and Bowman, 1917). King (1937) mapped the Marathon and Monument Spring quadrangles (Fig. 1). Eifler (1943) mapped the geology of the Santiago Peak quadrangle which adjoins the Buck Hill quadrangle on the east. Albritton and Bryan (1939) studied the Quaternary deposits of the Davis Mountains, including the northern part of the Buck Hill quadrangle. Lonsdale (1940) studied the igneous rocks of the Terlingua-Solitario region in southern Brewster and Presidio counties.

Hardin's map of the Elephant Mountain area is reproduced in Plate 6. The base map is an enlargement of the U. S. Geological Survey topographic map of the Alpine sheet, a 30-min-

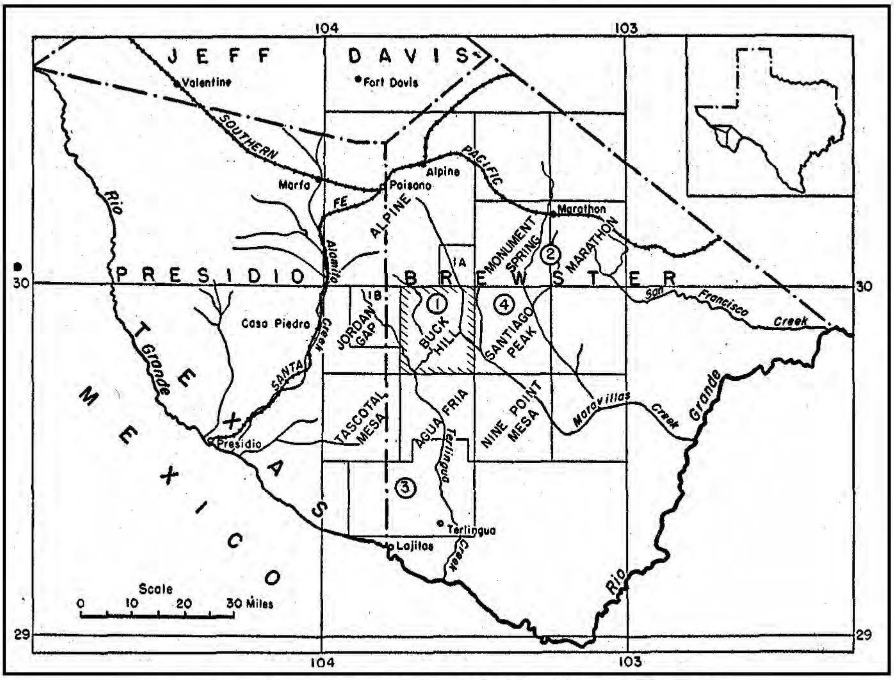

FIGURE 1.—INDEX MAP OF A PART OP TRANS-PECOS TEXAS

Showing Buck Hill quadrangle (1), Elephant Mountain area (1A), Paradise Valley area (IB), and related areas of published maps: (2) Monument Spring and Marathon quadrangles, King (1937); (3) Terlingua-Solitario region Lonsdale (1940); (4) Santiago Peak quadrangle, Eifler (1943).

ute quadrangle (1:125,000) surveyed in 1893. The detail of this old map did not permit a close tie with the Buck Hill quadrangle, especially on the rugged slopes of Elephant Mountain. Additional field work was done by Goldlich in 1946.

Scope of Field Work

Good exposures of the Tertiary volcanic rocks and the underlying Cretaceous strata in the Buck Hill quadrangle make this area favorable for detailed studies of the Tertiary stratigraphy and petrology of the southern Davis Mountains. This investigation was started by Elms (1937) in the summer of 1936 and was continued and expanded by the writers in the summer of 1940. It became apparent that additional mapping and tracing of the rock units recognized in the Buck Hill quadrangle in adjacent areas was desirable. Reconnaissance mapping of the Elephant Mountain area in the southeastern part of the Alpine quadrangle was undertaken by Hardin (1942), and of the Paradise Valley area in the northeastern part of the Jordan Gap quadrangle by Graham (1942) during June and July 1941 under the supervision of Goldich.

Acknowledgments

The writers are indebted to Charles Laurence Baker for his stimulating interest and helpful criticism. Mr. J. E. Wilson assisted in the field work in 1936; R. W. Graves, Jr., and G. C. Hardin, Jr., in 1940; Hardin and D. W. Graham, in 1941; and C. L. Seward, in 1946. The paleontologic determinations contributed by a number of geologists indicated in the text are gratefully acknowledged.

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of a part of the field work and of most of the chemical work which was done in the Rock Analysis Laboratory of the University of Minnesota by arrangement with Frank F. Grout. This generous co-operation is appreciated.

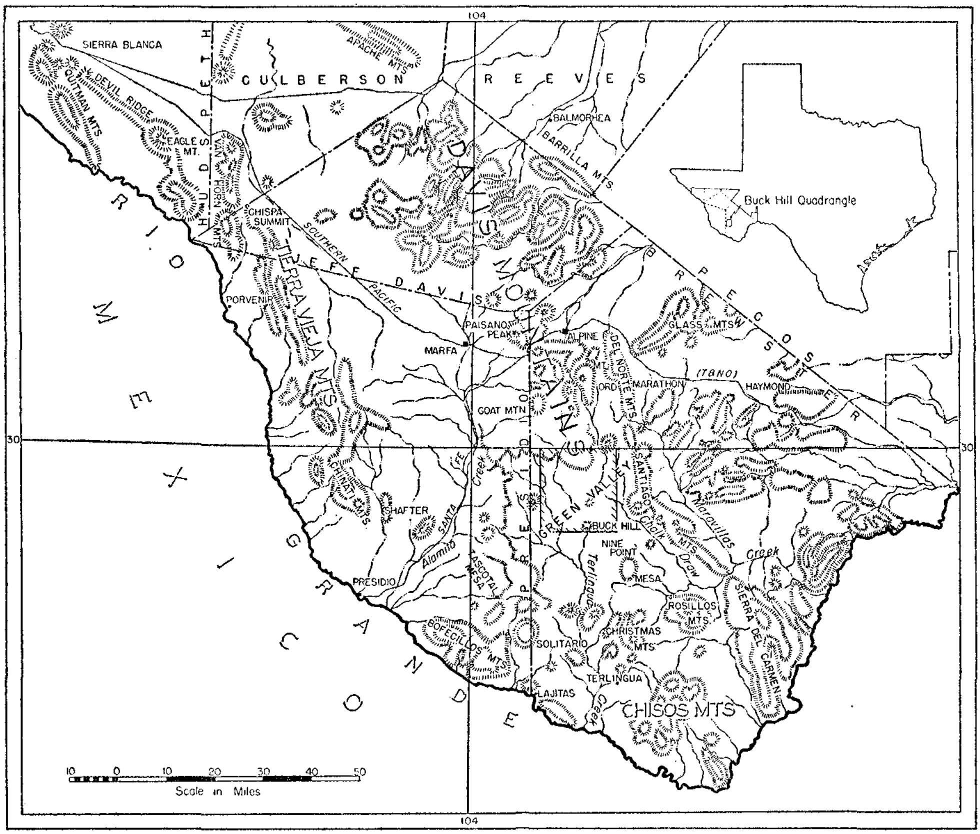


FIGURE 2.—SKETCH MAP OF A PART OF TRANS-PECOS TEXAS SHOWING PRINCIPAL PHYSIOGRAPHIC FEATURES AND LOCATION OF BUCK HILL QUADRANGLE

Field work in 1946 and the preparation of the manuscript were done under the auspices of the Bureau of Economic Geology, The University of Texas, and valuable suggestions and criticism were received from staff members. This paper is one of a series reporting results of a Trans-Pecos Texas project sponsored by the Bureau of Economic Geology.

GEOGRAPHY

Physical Features

The Davis Mountains (Fig. 2) in northern Brewster and Presidio counties were carved out of a thick accumulation of volcanic tuff with numerous intercalated lava flows. The succession is pierced by many igneous masses. Late orogeny resulted in broad open folds in the Tertiary volcanics and in faults with a displacement of as much as 1000 feet, but the physiographic development of the region was largely controlled by differential erosion. Greater resistance of the flows and intrusives to erosion resulted in mesas and in prominent peaks.

Some of the most picturesque mesas of the southern front of the Davis Mountains extend into the northern part of the Buck Hill quadrangle. In the northeastern corner (Pl. 1) is the southern tip of Elephant Mountain which dominates the region with its great bulk and altitude of over 6000 feet above sea level. A massive caprock of microsyenite accounts for this large erosional remnant. West of Elephant Mountain is Crossen Mesa capped by a thick flow of trachyte, and in the northwestern corner of the quadrangle is Mitchell Mesa with the southern tip of its rhyolite caprock rising 5351 feet above sea level. South of these mesas are lower ones capped with basalt. Their southern scarps face Green Valley which occupies the central and southwest part of the quadrangle. On the southeast, hills of Cretaceous limestone rise above the alluvium of Green Valley. The nearly horizontal Cretaceous strata continue eastward in the Santiago Peak quadrangle where they have been sharply upturned and thrust-faulted in the Santiago Mountain range.

Green Valley was formed during an earlier erosion cycle, and the alluvium of the valley now is being dissected and removed by the streams. The western part of the quadrangle is drained by Terlingua Creek, and the eastern part by the westernmost tributary of Maravillas Creek known here as Calamity Creek. The drainage divide in the quadrangle is poorly defined, and the surface water may pass from one drainage system into the other; yet the two streams join the Rio Grande 50 miles apart (Fig. 1). The streams have cut deep steep-sided channels in the alluvium of Green Valley and have renewed attack on the bedrock.

In the southern part of the quadrangle syenitic intrusives form Straddlebug Mountain and Buck Hill. In the southeastern corner prominent scarps are formed by the Cretaceous limestones.

Erosional Agencies

The chief erosional agency is running water. Although the annual rainfall is small, much of it comes as torrential downpours. Sheet wash is effective on the steep slopes. Undermining, sapping, and marginal fragmentation wear the more resistant rocks such as the igneous flows which cap the mesas. In this process the vertical joints, which permit downward seepage of water favoring weathering and spalling, are an important factor in the wasting and recession of the cliffs. Although the wind appears to blow constantly and occasionally reaches hurricane velocity, it is of secondary importance; the scanty vegetation of the region is much more effective against wind than against water erosion.

Climate and Vegetation

The Buck Hill quadrangle with an average annual rainfall of less than 15 inches is in the driest climatic province of Texas. Most of the rainfall comes during the hot summer months as thunder showers of short duration but often of great intensity and sometimes accompanied by violent winds. Temperatures during the day in the summer commonly are above 100°, but the nights are cool. The average mean annual temperature for Brewster County is approximately 63°.

The sparse vegetation includes a great variety of yuccas, cacti, and other hardy plants adapted to the semiarid climate. The relative abundance of certain plant types shows a response to physical factors. On valley flats sagebush and creosote are abundant. Dense growths of ocotillo characterize upland flats of volcanic tuff and breccia and are common on weathered slopes of andesite, basalt, and certain limestone formations. Rough hills and slopes have considerable sotol and lechuguilla. Ravines with better than average supply of water may. be choked with catclaw, and occasionally cottonwood trees are found, as at Cottonwood Spring. Bunch grass is plentiful on the mesas but relatively scarce on many of the valley flats.

CRETACEOUS SYSTEM

General Features

The Cretaceous formations (Table 1) represented in the Buck Hill quadrangle are the Georgetown limestone, of which only the upper 127 feet is exposed, the Grayson clay (Del Rio), the Buda limestone, and the Boquillas formation, which was eroded in part prior to the deposition of the Tertiary volcanics. The Cretaceous formations in this part of Trans-Pecos Texas are readily differentiated lithologically, but in comparison with north and south Texas the section is not well known, and there are many stratigraphic and paleontologic problems.

The Georgetown formation is a thick-bedded, commonly massive limestone. The Grayson is mainly clay and shale with a few thin calcareous sandstone beds near the top of the formation which contain abundant *Haplostiche texana* (Conrad), a large foraminifer. The Buda is chiefly thick-bedded, fine-grained, gray to white limestone with a nodular marly middle unit

TABLE 1.—*Geologic formations in the Buck Hill quadrangle*

Age	Group	Formation	Thickness in feet	Correlation	Lithology and remarks
Quaternary		Alluvium	30 ±		Recent and older (Pleistocene?) unconsolidated silt and gravel.
		—— Angular unconformity ——			
	Buck Hill volcanic series	Mitchell Mesa rhyolite	38– 150	Probably equivalent in part to Chisos beds, Vieja series, Square Peak volcanic series, etc.	Gray to pink rhyolite porphyry.
(Oligocene?)	Buck Hill volcanic series	Duff tuff	1000–1400		Tuff, breccia, and conglomerate.
Tertiary	Buck Hill volcanic series	Cottonwood Spring basalt	50–325+		Fine- to medium-grained basalt flows; dense to amygdaloidal; nonporphyritic.
(Eocene?)	Buck Hill volcanic series	Pruett tuff and intercalated flows: Crossen trachyte, Sheep Canyon basalt, and Potato Hill andesite	900–1000		Tuff, breccia, conglomerate, arkose, fresh-water limestone; intercalated porphyritic flows of trachyte, basalt, and andesite.
		—— Angular unconformity ——			
Upper Cretaceous	Austin group	Undivided, included with Boquillas	210–300 (?)	Austin	Upper surface eroded. Limestone with calcareous shale near top.
	Eagle Ford group			Eagle Ford	Alternating shale and limestone flags in lower part.
		—— Disconformity ——			
Lower Cretaceous	Washita group	Buda	65–68	Buda	Thick-bedded limestone with middle nodular marly unit.
		—— Disconformity ——			
	Washita group	Grayson	60–76	Grayson	Clay and shale with thin calcareous sandstone layers.
	Washita group	Georgetown	127+	Georgetown	Massive, thick-bedded limestone; more thinly bedded in upper part.

which commonly is fossiliferous. The lower part of the Boquillas is typically thin argillaceous limestone flags separated by shale. The upper part is largely fine-grained, evenly bedded limestone with beds of marl or calcareous shale becoming thicker and more numerous near the top of the formation.

Georgetown Limestone

The larger of the two outcrops of the Georgetown formation in the Buck Hill quadrangle is in the southeastern corner (Pl. 1) just east of Stone Tank and continuing eastward in the Santiago Peak quadrangle. Here, along the Chalk Draw fault the Georgetown makes a prominent northward-facing cliff 100 feet high of massive limestone, except for the upper 38 feet which is distinctly bedded. Near Stone Tank a maximum exposed thickness of 127 feet of the Georgetown was measured. The outcrop is up to 1 mile wide, and the nonresistant Gray son formation has been stripped from most of its surface except for a small hill which is protected by a cap of the Buda limestone. The second exposure is on an east-west fault southeast of Elephant Mountain where a narrow strip of Georgetown limestone crops out.

The Georgetown limestone is gray to brownish gray and weathers to a dirty gray or white, rough, and etched surface. Potholes are common along creek beds, and the bare flat surfaces are covered with tinajitas or etched potholes (Udden, 1925). Beds in the lower part of the exposed formation are 10–15 feet thick, and these thick layers make the formation one of the most resistant in the area and form vertical cliffs and overhanging ledges. The upper 38 feet of the limestone is nodular, thinner-bedded, and fossiliferous. The texture ranges from fine- to coarse-grained. Fossil fragments which are numerous and scattered throughout the limestone are recognizable by their crystalline calcite. The lower 8 feet contains some chert in the vicinity of Stone Tank.

Only the upper contact of the Georgetown limestone is exposed, and near the base of Elephant Mountain the contact with the overlying Grayson is gradational. A 4-foot thickness of the Georgetown is overlain by nodular, marly, thin-bedded limestone, the *"Acanthoceras cunningtoni* zone" (Adkins, 1932, p. 388), of the Grayson formation, which grades upward to a shell bed, 2–4 feet thick, composed almost entirely of the ramshorn oyster, *Exogyra arietina* Roemer, and of sandy marly clay in which this fossil is abundant, In the upper 50 feet of the Georgetown near Stone Tank, and in particular in the upper 38 feet of relatively thin-bedded limestone, fragmentary fossil remains are abundant, but few forms are identifiable. The brachiopod *Kingena wacoensis* (Roemer) is common in the upper 38 feet and extends about 15 feet lower. *Exogyra arietina* Roemer extends from the Grayson down about 8–10 feet in the Georgetown. One specimen of *Trigonia* sp. was found 8 feet below the top of the formation, and broken specimens of *Pecten* and *Gryphaea* were collected in the upper zone about 2 miles east of Stone Tank. The upper part of the Georgetown contains a Main Street fauna, but lack of identifiable fossils in the lower thick-bedded limestone precludes correlation with other faunal zones described by Adkins (1927, p. 50) in the Fort Stockton section where alternating limestone and marl beds of Georgetown equivalent have a total thickness of 245 feet. In southern Trans-Pecos Texas limestone replaces much of the marl of the Fort Stockton section, and the resultant massive reeflike limestone which is in part equivalent to the Georgetown formation (Washita group) and in part to older formations, Kiamichi and Edwards (Fredericksburg group), was named the Devils River limestone (Udden, 1907a). Recent work in areas east of the Buck Hill quadrangle shows that the fossiliferous gray to brown Kiamichi clay can be recognized, and the Devils River formation can be subdivided.

Grayson Clay

The largest outcrops of the Grayson (Del Rio) formation are in the southeastern part of the quadrangle. A good exposure is readily accessible just east of the Alpine-Terlingua highway south of the junction with the road to Marathon. The Grayson is 76 feet thick here and is capped with thick beds of the Buda limestone. East of Stone Tank the formation is about 70 feet thick, and its outcrop can be followed eastward into the Santiago Peak quadrangle. The beds dip less than 2° to the south. Southeast of Elephant Mountain the Grayson is exposed in the scarp of a low southward-facing cuesta capped by Buda limestone. The outcrop is complicated by numerous faults and minor folds, but the average dip is about 3° to the northeast. In the channel of Calamity Creek 4¼ miles south of the Kokernot ranch house there are small outcrops where much of the Grayson clay is eroded from beneath the Buda limestone leaving the latter as an overhanging ledge. Here the dip is approximately 4° N, The Grayson is about 60 feet thick in the northern part of the quadrangle.

The Grayson formation is dominantly clay-shale but also contains thin flags of limestone and sandstone. The clays usually are light buff, tan, or light greenish yellow, weathering to a characteristic tawny yellow with locally abundant secondary gypsum and limonite. The flags are most abundant near the top of the formation and are dark to light gray, usually very sandy, nodular and lenticular; a bed 6 inches thick may disappear laterally within a distance of 50 feet. The middle and lower parts are usually covered with slumped clay, so that fresh exposures are rare. The detailed section of the upper part measured in Calamity Creek (Appendix, Section No. 1) is typical of the formation in the central and southern parts of the quadrangle. At the foot of Elephant Mountain (Appendix, Section No. 2) and elsewhere in the northern part of the Buck Hill quadrangle, the upper part of the Grayson contains relatively more sand.

The contact of the Grayson with the underlying Georgetown rarely is exposed, but at Elephant Mountain the lower contact is conformable and gradational. The contact with the overlying Buda is an undulating surface with a sharp break from clay of the Grayson to nodular limestone of the Buda. In the Buck Hill quadrangle there are no marked indications of an unconformity, but elsewhere in Trans-Pecos Texas the Grayson formation is variable in thickness and locally absent. East in Val Verde County in road cuts on U. S. Highway 90, 1.3 miles east of Comstock, L. W. Stephenson found included in the lower beds of the Buda limestone cobbles and boulders derived from *Exogyra arietina* shell layers of the Grayson formation.

Fossils collected from the Grayson in the Buck Hill quadrangle are typical of the south Texas Grayson fauna. Three fossil localities are shown on the map: (1) near the base and southeast of Elephant Mountain, (2) in Calamity Creek, 4½ miles south of the Kokernot ranch house, (3) at the small hill (3970 feet) It-miles east of Stone Tank. The ammonite *Turrilites brazoensis* Roemer occurs near the base of the formation. *Exogyra arietina* Roemer ranges 30 feet up from the base but was not found in the upper half of the formation. The arenaceous foraminifer *Haplostiche texana* (Conrad) is abundant throughout, especially in the sandy flagstones. About 2 feet below the top of the formation at the Elephant Mountain locality is a conspicuous shell bed, 4 inches thick, which contains abundant *Exogyra cartledgei* Böse, *Gryphaea graysonana* Stanton, *Exogyra whitneyi* Böse, *Ostrea* sp., and *Pecten* fragments. *Heteraster inflatus* (Cragin) is abundant in the upper part of the formation.

A large collection of dwarfed limonitic ammonites and echinoids was made at the Stone Tank locality, but this collection has not been studied. Most of the fossils listed were collected in either the lower 6 feet or upper 20 feet of the formation:

Haplostiche texana (Conrad)
Holectypus cf. *limitis* Böse
Heteraster inflatus (Cragin)
Protocardia texana (Conrad)
Inoceramus spp.
Pecten (Neithea) budensis Kniker
Exogyra arictina Roemer
cartledgei Böse
whitneyi Böse
Gryphaea graysonana Stanton
Ostrea sp.
"Acanthoceras" sp. aff. A. *cunningtoni* Böse
Turrilites brazoensis Roemer
Engonoceras sp.

Buda Limestone

The principal outcrops of the Buda limestone are along Calamity Creek north of the Walnut Draw fault and in the southeastern part of the quadrangle south of the Chalk Draw fault. The Buda also is exposed southeast of Elephant Mountain and on the northwest flank of Straddlebug Mountain in the southwestern part of the quadrangle where the Cretaceous rocks have been domed by a small syenite intrusive. Erosion has stripped the less resistant flags of the overlying Boquillas leaving wide flat surfaces of the white to gray fine-grained nodular Buda limestone. Commonly a heavier growth of ocotillo serves to differentiate the Buda outcrops from the Grayson and Boquillas. Although in places the Buda resembles the Georgetown limestone, its lighter color and more distinct bedding generally identify it.

The Buda of this area commonly has three lithologic facies: upper and lower units of thick-bedded, light-gray, fine-grained to porcelaneous limestone and a middle unit of light-gray to buff marl and thin-bedded nodular limestone. The upper and lower units with beds 4–6 feet thick form cliffs or steep slopes; the middle unit weathers to a gentle slope. At Elephant Mountain the Buda is 65 feet thick with a middle marly unit of 16 feet. In Calamity Creek the middle marly unit is 20 feet thick. Although the section (Appendix, Section No. 1) measured in Calamity Creek is incomplete, it is representative of the Buda lithology. Two miles east of Stone Tank the formation is 68 feet thick, and the marly unit measures 18 feet.

The Buda generally is fossiliferous with the middle marly unit affording the best material. Good fossil localities along Calamity Creek are indicated on the map (PL 1). The echinoid *Hemiaster calvini* Clark is abundant and marks a horizon about 20 feet above the base of the formation in the lower part of the middle marly unit. About 2 feet above the *Hemiaster* horizon is a 4-foot zone in which *Pecten* predominates. A third zone 2–4 feet higher is characterized by *Leiocidaris hemigranous* (Shumard). Ammonites were collected in all the zones, but these have not been studied in detail; *Budaiceras* spp. occur lowest in the section with *Hemiaster calvini* Clark.

Two fossil crab specimens from the middle marly unit were identified as *Graptocarcinus texanus* Roemer by Stenzel. The species was first described (Roemer, 1887) from the Buda limestone in Austin, Texas, and redescribed by Stenzel (1944). It had hitherto not been known outside of central Texas.

Fossils found in the Buda formation in the Buck Hill quadrangle are:

Hemiaster calvini Clark
Heteraster cf. *traski* (Whitney)
Leiocidaris hemigranosus (Shumard)
Protocardia texana (Conrad)
Salenia sp.
Pecten (Neithea) texanus Roemer
(Neithea) whitneyi Kniker
(Neithea) subalpinus Böse
(Neithea) subalpinus var. *linki* Kniker
Nautiloid sp.
Turrilites sp.
Budaiceras spp.
Craptocarcinus texanus Roemer

Boquillas Formation

All the strata above the Buda limestone and below the basal Tertiary conglomerate in the Buck Hill quadrangle are tentatively assigned to the Boquillas formation. Clayey and sandy limestone flags alternating with beds of shale are typical of the lower part of the formation. This succession is similar to the beds above the Buda limestone in southern Brewster County named by Udden (1907b, p, 29–32) the Boquillas flags. The upper beds are mainly limestone with some marl and shale which may be equivalent to part of Udden's (1907b, p. 33) Terlingua beds. How much of the Boquillas is Eagle Ford and how much Austin equivalent cannot be said; zoning or redefining of the Boquillas must await more detailed studies.

Large areas in the eastern part of the quadrangle are covered by the Boquillas formation (Pl. 1). South of the Chalk Draw fault the lower flaggy Boquillas caps the upthrown block east of the Terlingua highway. In the downthrown block the Boquillas beds dip south and rest against the Georgetown, the Grayson, and the Buda formations. West of the highway in the vicinity of Buck Hill the upper limestone beds cap the upland south of the Chalk Draw fault. North of Chalk Draw road an extensive outcrop of the Boquillas is cut off by a northwest-southeast fault west of Butcherknife Hill where the Pruett tuff is downfaulted against the limestone. This outcrop, 3–4 miles wide, extends eastward into the Santiago Peak quadrangle.

In the northeastern part of the quadrangle the Boquillas forms a southward-facing escarpment along the Walnut Draw fault extending from a point just east of Whirlwind Spring beyond the eastern boundary of the quadrangle. Most of the downthrown block south of the Boquillas escarpment is covered by alluvium, but east of Calamity Creek upper Boquillas limestone capped with a small remnant of the Preutt tuff is downthrown against the lower flags. The Boquillas also crops out southeast of Elephant Mountain, and the lower flags form a crescent-shaped outcrop around the syenite core of Straddlebug Mountain.

The gray to tan or brown limestone flags and interbedded shale in the lower part of the Boquillas formation are easily recognized. In the lower 50 feet, limestone flags, 2–4 inches thick, and shale beds, 3–4 feet thick, are evenly spaced, and because the shale is less resistant it erodes in a "stairstep" topography in which the flags form treads at 3- to 4-foot intervals. A sample of the flags dissolved in dilute hydrochloric acid gave an insoluble residue of about 14 per cent by weight. Most of the insoluble material is finely divided clay mineral of the montmorillonite group. The larger clastic grains are silicic plagioclase and microcline; quartz is rare. On many of the thinner flags there are markings which Udden (1907b, p. 32) described as fossil ice crystals.

The upper part of the Boquillas is mainly grayish-white to buff limestone weathering to light gray or white. The rock is fine-grained and uniform, locally with pyrite concretions which are commonly altered to limonite. The beds range from 1 inch to 4 feet thick, and the thicker beds of light-colored limestone differentiate the upper part of the Boquillas from the lower brown flaggy unit. There are some shale or marl breaks, however, and the distinction between lower and upper units on lithologic characters is not made easily everywhere. Calcareous shale in the upper part of the Boquillas beneath the basal Tertiary conglomerate is exposed just south of the Terlingua road ¼ mile southeast of the highway bridge on Calamity Creek Wash and at Hill 3927 approximately 2¼ miles southeast of the bridge and 2½ miles northeast of Butcherknife Hill. The fresh shale is gray, weathering to a yellow brown or tawny yellow. At Hill 3927 the calcareous shale is 30 feet thick and resembles Terlingua beds along Terlingua Creek south of the Buck Hill region, but the outcrop is limited, and alluvium obscures the relations with the Boquillas limestone.

Because of pre-Pruett as well as recent erosion and because of faults and local thick cover of alluvium, a satisfactory measurement of the thickness of the Boquillas could not be made in the Buck Hill quadrangle. In the southern part of the quadrangle beds assigned to the Boquillas aggregate 210 feet. Near Stone Tank the lower flaggy beds are 130–140 feet thick. The measured section (Appendix, Section No. 3) southeast of Elephant Mountain includes 64 feet of typical lower flaggy beds and about 53 feet of upper limestone beds. The upper part of the section is covered, and probably 20 feet of additional strata beneath the Pruett tuff can be assigned to the Boquillas giving a total thickness of 127 feet. The formation probably is thickest in the hills east of Calamity Creek southeast of the Kokernot ranch house. Although no measurement was made, the maximum thickness is thought to be less than 300 feet.

The Boquillas and the underlying Buda in the Buck Hill quadrangle are concordant, but there is a marked lithologic change from the uppermost light-gray, thick limestone bed of the Buda to the lowermost dark-gray, sandy, banded, thin limestone flags of the Boquillas. Roberts (1918, p. 20) discusses the disconformable relations of the Boquillas to the Buda in Val Verde County. In road cuts along U. S. Highway 90 near Langtry the lowermost Eagle Ford bed is a sandy limestone. The contact with the underlying Buda, like that in the Buck Hill region, generally is undulating, but locally in these road cuts the basal Eagle Ford limestone is conglomeratic.

The upper contact of the Boquillas formation in the Buck Hill quadrangle is an erosion surface unconformably overlain by the basal conglomerate and conglomeratic sandstone of the Pruett formation. At some localities, as on either side of the O2 ranch road, 1½ miles northeast of Whirlwind Spring, the conglomeratic sandstone of the Pruett rests on limestone. At other places, such as Hill 3927, the basal conglomerate lies on stratigraphically higher beds of calcareous shale.

Identifiable fossils in the Boquillas are rare. Imprints of *Inoceramus* are abundant but cannot be identified specifically. The thin sandy flags, 12–20 feet above the base of the formation, contain a poorly preserved ammonite fauna which according to W. S. Adkins (personal communication, 1936) appears to be an unrecorded assemblage. Fragments of a fossil fish from the upper limestone were examined by the late Curtis J. Hesse (personal communication, 1937) who wrote:

"Your specimen is very incomplete, too much so for accurate determination. However, it appears to be similar to *Ferrifrons rugosus,* a fish described by D. S. Jordan (Univ. of Kansas Sci. Bull, vol. 15, No. 2, p. 228, pl. 18–19, 1924), from the Niobrara Chalk of Kansas. This, of course, is a somewhat meaningless name since Jordan could not tell what the fish was related to; but it is interesting that the two records should be of approximately the same stratigraphic position."

The calcareous shale below the basal Pruett conglomerate at Hill 3927, northeast of Butcherknife Hill, contains impressions of ammonites and pelecypods, but these are unidentifiable. Foraminifera were noted in a disintegrated and washed sample, and a study of the microfauna was generously undertaken by Dr. D. L. Frizzell and Miss Glenn G. Collins of the Department of Geology, The University of Texas. Frizzell (personal communication, 1947) wrote:

"Foraminifera are moderately common but in small variety, only seventeen species having been found in the sample. Although the following list of identifications is to a degree tentative, a correlation with the lower part of the Austin group seems definite.
Trochammina sp.
Lenticulina sp. aff. *L. münsteri* (Roemer)
Dentalina, 2 spp.
Gümbelina moremani Cushman
G. *pseudotessera* Cushman
G. sp. cf. *striata* (Ehrenberg)
Bulimina fabilis Cushman and Parker
B. sp. cf. *B. reussi* Morrow
Neobulimina irregularis Cushman and Parker
Valvulineria sp.
Globigerina sp.
Hastigerinella alexanderi Cushman
H. watersi Cushman
Globotruncana canaliculata (Reuss)
G. fornicata Plummer
Planulina austiniana Cushman"

Because of its stratigraphic position above the Buda limestone the lower part of the Boquillas formation in the Buck Hill quadrangle is correlated with the Eagle Ford; the uppermost part, from the fossil data now available, is lower Austin. Much remains to be done in the study of the fauna of the Boquillas in the Buck Hill quadrangle and in Trans-Pecos Texas. In this study the Forminifera will provide valuable information to supplement the megafossils.

TERTIARY SYSTEM

Buck Hill Volcanic Series

Principal features.—The Buck Hill volcanic series is chiefly tuff with subordinate conglomerate, sandstone, breccia, and fresh-water limestone and intercalated lava flows ranging from basalt to rhyolite (Fig. 3). The volcanic series lies with angular unconformity on the Boquillas formation in the Buck Hill quadrangle, and the base of the Pruett formation is marked by a limestone pebble conglomerate and conglomeratic arkosic sandstone. Intercalated with the Pruett beds are the Crossen trachyte, the Sheep Canyon basalt, and the Potato Hill andesite. These flows came into the Buck Hill region from the north, and their mapped boundaries probably represent their original southern limits fairly closely. The flows were eroded in part and weathered before being covered with ash. The Pruett formation is 900–1000 feet thick. In the northern part of the quadrangle the intercalated lavas make up 300–400 feet of the total thickness, but south of Crossen Mesa the whole thickness is tuff and related sediments.

The top of the Pruett formation is placed at the base of the Cottonwood Spring basalt flows which are variable in number and thickness, ranging from 50 to 325 feet or more. The flows are overlain by the Duff formation which is over 1000 feet thick and is chiefly rhyolitic tuff with some breccia and local conglomerate beds. The top of the Duff tuff is the base of the rhyolite capping Mitchell Mesa. West and southwest of the Buck Hill quadrangle the Mitchell Mesa rhyolite is overlain by a third major unit of tuff, tuffaceous sand, and thick flows of andesite-basalt totaling about 1000 feet, so that the Tertiary volcanic succession in this part of Trans-Pecos Texas has a minimum thickness of 3000 feet and may be as much as 4000 feet thick.

Age and correlation.—The Buck Hill volcanic series is of lower Tertiary age and is equivalent, in part at least, to volcanic successions in other parts of Trans-Pecos Texas. The Pruett formation is assigned tentatively to the Eocene; the Duff, to the Oligocene.

A collection of silicified gastropods from tuffaceous fresh-water limestone of the Pruett formation in Sheep Canyon in the Alpine quadrangle (Fossil locality, Pl. 6) was examined by Mr. Paul Bartsch of the U. S. National Museum for Hardin (1942). A *Physa,* the tips of *Goniobasis,* and the youthful form of *Cochliopa* were identified. Bartsch concluded that the *Goniobasis* specimens may belong to the group including *tenera carterii*. *Goniobasis tenera carterii* Conrad is described from the lower Eocene of western Wyoming, western Colorado, and northern New Mexico (Hender-

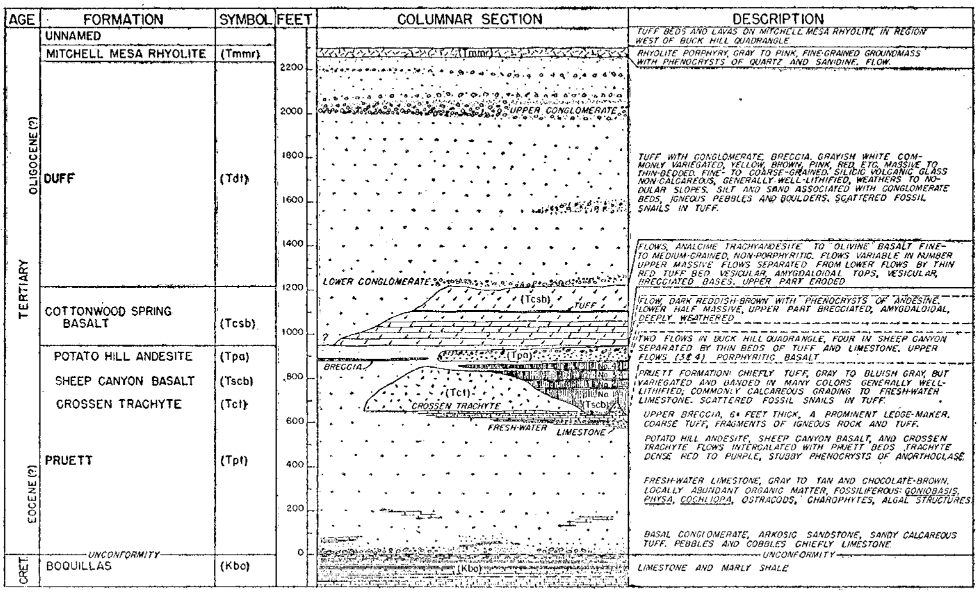


FIGURE 3.—COLUMNAR SECTION OF THE BUCK HILL VOLCANIC SERIES

son, 1935, p. 227). A few ostracods and charophytes in insoluble residues of the limestone were examined by Mr. R. E. Peck (Hardin, 1942) who found the internal molds of *Metacypris, Cypris,* and varieties of that genus, *Paracypris* and *Bairdiocypris,* etc.; and unidentifiable charophytes. None of these forms is diagnostic. Fresh-water limestone beds between flows of the Sheep Canyon basalt on the southern slope of Elephant Mountain contain a similar fauna. The assignment of the Pruett to the Eocene is on the basis of abundant specimens of *Goniobasis* in fresh-water limestone lentils in the upper part of the formation.

Low-spired fossil snails were collected from the lower Pruett tuff beds near the base of Crossen Mesa about 1 mile east of the Pruett ranch house and from near the base of Elephant Mountain. Similar large low-coiled snails, 2–3 inches in diameter, were collected by Graham (1942) from the Duff tuff at Church Mountain in the southeastern part of the Jordan Gap quadrangle. Land snails from the 02 ranch examined by Junius Henderson (Adkins, 1932, p. 514) are identical with the snail described by Cockerell (1914) as *Helix hesperarche*. Cockerell's specimen came from the Cope collection, and, although it was labelled "either Puerco or Torrejon, probably Torrejon", its original locality cannot be established. The specimen may have come from the Buck Hill volcanic series of Texas rather than from the Eocene Torrejon of New Mexico (Henderson, 1935, p. 134).

The Duff formation is assigned to the Oligocene on the basis of a smaller gastropod associated with *"Helix" hesperarche* at Church Mountain and also found in other places in the Jordan Gap quadrangle. It is similar to a species occurring in the Oligocene Vieja volcanic series in the Tierra Vieja Mountains, western Presidio County (Fig. 2). The volcanic succession of the Tierra Vieja Mountains, Rim Rock country, was first studied by Vaughan (1900), who assigned it to the Cretaceous. In 1946 Mr. Bryan Patterson of the Chicago Natural History Museum collected vertebrates and gastropods from the lower Vieja tuff beds northwest of Porvenir (Fig. 2). Patterson (personal communication, 1947) states that the tuff beds are earliest Oligocene with a fauna equivalent to that of the Chadron formation. The gastropods associated with the vertebrate fossils were identified as *Mesodon* (*"Helix"*) *leidyi* (Hall and Meek) by Dr. L. S. Russell (personal communication, 1947) who states that the Duff tuff specimens probably are the same species.

A brief reconnaissance of the Porvenir area was made by Goldich with Patterson in November 1946. The basal conglomerate of the Vieja series lies with marked angular unconformity on the truncated steeply dipping Upper Cretaceous (Navarro) sediments. The volcanics have been deformed into broad folds with dips of 10°–15° on the limbs. There is a clear-cut angular unconformity between the Vieja tuff beds and the over-lying "lake beds" of Pliocene (?) age. Normal faults of considerable magnitude displacing the Vieja series and older rocks have been described by Baker (1941). The basal conglomerate contains many igneous pebbles and boulders, some 3 feet or more in diameter, in addition to limestone pebbles and cobbles. The conglomerate is 20–30 feet thick and is overlain by an equal thickness of tuff which is succeeded by thin flows of perlite and of trachyte. Only 3–4 feet of the perlite immediately below the trachyte is exposed. The trachyte, averaging 25–30 feet thick, is overlain by 400–500 feet of tuff capped by a massive igneous rock which Lord (1900) described as quartz pantellerite. Patterson's collections were made from the tuff beds above the trachyte.

South of the Tierra Vieja Mountains in the Chinati range (Fig. 2) Tertiary extrusives lie on Cretaceous and Permian sedimentary formations (Ross, 1943). In the Quitman Mountains in Hudspeth County a succession of flows, breccia, and tuff, 3500 feet thick, rests on folded and eroded Eagle Ford and older Cretaceous rocks. Huffington (1943) named this succession the Square Peak volcanic series and assigned it to the lower Tertiary, Eocene, or Oligocene.

In the Barrilla Mountains, Jeff Davis and Reeves counties, 60 miles north of the Buck Hill quadrangle, Tertiary volcanics rest unconformably on "clays of Pierre Cretaceous (Upson clay, Taylor marls) age" (Baker and Bowman, 1917, p. 119). Fossil leaves collected by Baker from the basal rhyolitic tuffs were correlated with the flora of the Raton and Denver formations (lower Eocene) by Berry (1919). From tuff beds within 200 feet of the base of the volcanic series on the Casey ranch 11 miles east of Balmorhea (Fig. 2) in the northeastern part of the Davis Mountains, Baker (1934, p. 151) collected a fossil tooth which R. A. Stirton identified as that of *Hyracodon,* a lower or middle Oligocene rhinoceras.

The Buck Hill volcanic series probably is equivalent in part to the Chisos beds (Udden, 1907b) which include about 2000 feet of thin-bedded tuffaceous sediments above the Tornillo clay in the Chisos Mountains. Udden concluded that there is no break between the Chisos beds and the Tornillo which contains a large quantity of weathered volcanic material (bentonite), and he assigned the Chisos beds to the Cretaceous. Adkins (1932, p. 508–514) considers the Tornillo as probably uppermost Cretaceous. The Chisos beds are now generally considered Tertiary.

Pruett Formation

Definition and description.—The Pruett formation, named for the Pruett ranch in the north-central part of the quadrangle, is principally volcanic tuff but includes conglomerate, tuffaceous sandstone and breccia, and tuffaceous fresh-water limestone. Interfingering with the tuff are flows of trachyte, basalt, and andesite.

The Pruett beds are widely distributed in the Buck Hill quadrangle and adjacent areas. East of Calamity Creek in Elephant Mountain the tuff is 500–600 feet thick. The volcanic succession in the Elephant Mountain area is described in a later section. South of the mountain in the eastern part of the quadrangle there are small remnants of the basal Pruett beds on the Boquillas. A thickness of 500 feet of tuff was measured (Appendix, Section No. 4) in the first canyon north of the southeastern end of Crossen Mesa 2 miles southwest of the Kokernot ranch house. The base of this section is covered by alluvium and may be 100–200 feet above the Cretaceous basement, because there is a minimum thickness of 650 feet of the Pruett in the southern scarp of the mesa. On the mesa additional tuff beds with intercalated lavas rest on the trachyte, and this succession to the base of the Cottonwood Spring basalt is about 100 feet thick. If a thickness of 150 feet is assumed for the trachyte, a total thickness of at least 900 feet is indicated for the Pruett formation in the northern part of the quadrangle.

South of Crossen Mesa along the 02 ranch road the basal conglomeratic sandstone of the Pruett rests on Boquillas limestone. West of Whirlwind Spring the upper beds of the formation capped by the Cottonwood Spring basalt are exposed continuously, extending beyond the western boundary of the quadrangle into the Jordan Gap quadrangle. A 125-foot thickness of tuff was measured 1 mile south of Cottonwood Spring (Appendix, Section No. 5). Alluvium covers most of Green Valley, but the Pruett formation is exposed along Terlingua Creek, and along most of The Ditch and Calamity Creek Wash. The basal conglomerate and lower Pruett beds rest on the Boquillas limestone at Buck Hill and in a small graben 1 mile to the west.

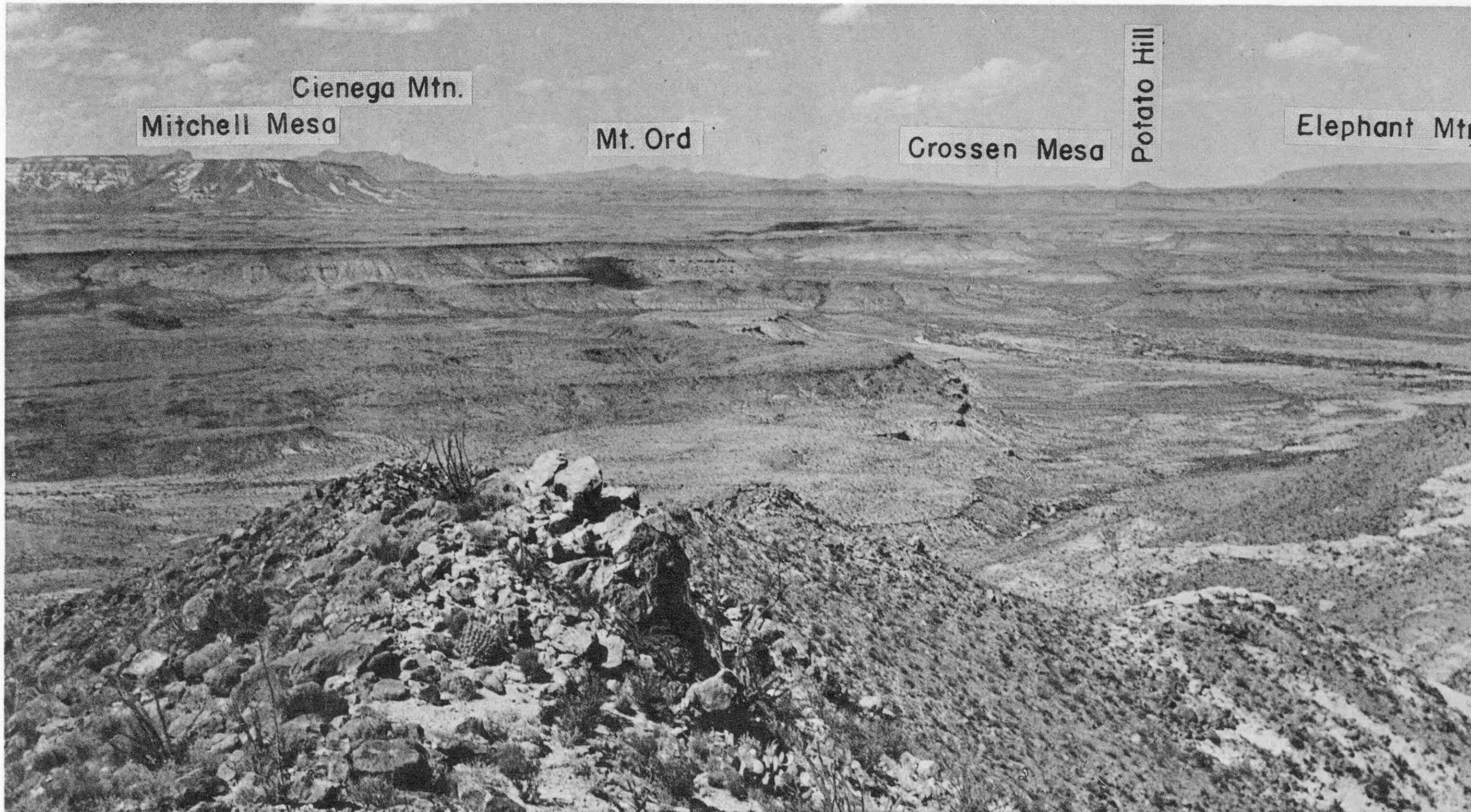
The Pruett tuff is grayish white, bluish gray, greenish gray, buff, brown, pink, and red. Fragments commonly differ in color from the matrix, and speckled color combinations result. Locally hard, dense, and silicified layers grade to loose, friable ash, but on the whole the tuff is well indurated. Much of the Pruett is massive and thick-bedded, but thin-bedded, well-stratified material is common. Stratified, varicolored beds are strikingly exposed at Boat Mountain (Pl. 3, fig. 2), a spurlike prominence protected from erosion by a thick bed of breccia-conglomerate. Except where protected by the breccia-conglomerate or by the overlying flows of the Cottonwood basalt, the tuff is easily eroded and forms low rounded hills. It weathers to nodular forms, and slopes generally are littered with small hard pellets and nodules which roll easily making walking difficult.

There are few easily recognizable units in the Pruett formation which can be used for correlating separated sections, and faults are difficult to recognize and follow in the tuff unless one side of the fault is marked by an igneous rock or by Cretaceous strata. There are, however, three distinctive lithologic facies. They are tentatively proposed as members: (1) conglomerate and sandstone which are widespread at the base of the formation, (2) fresh-water limestone which in Crossen Mesa underlies the trachyte caprock, 500–600 feet above the base of the formation, and (3) breccia-conglomerate which occurs 60 feet below the top of the Pruett formation.

Basal conglomerate and sandstone.—The conglomerate at the base of the Pruett formation consists chiefly of well-rounded pebbles and cobbles of dense, light-tan to dark grayish-brown limestone with some marble, quartzite, petrified wood, and variously colored chert pebbles. It is characterized by flat pebbles of fibrous calcite which are pieces of *Inoceramus* shells. Pebbles of igneous rock are rare, requiring careful search, in contrast with their abundance in the breccia-conglomerate member near the top of the formation. The conglomerate grades up to coarse, cross-bedded conglomeratic sandstone.

The conglomerate, tuffaceous sandstone, and related beds are well exposed in a number of places in the eastern part of the quadrangle. Along the 02 ranch road south of Crossen Mesa where the conglomerate rests on thin-bedded Boquillas limestone, angular slabby blocks of the limestone are contained in the conglomerate which ranges from 2 inches to 1 foot in thickness and grades up to coarse-grained tuffaceous grit and sandstone. Approximately 2½ miles to the northwest in a small hill just below Crossen Mesa and three-fourths of a mile east of the Pruett ranch house, the lower tuff beds include a sandstone layer. The section measured in the small hill follows:

Unit	Description	Thickness in feet
6.	Tuff, hard, purplish with small white grains	30
5.	Tuff, hard, dense, pink to purplish	1
4.	Sandstone, tuffaceous, gray with a few black grains; well indurated (Sample No. 872). Pebbly layer 1–2 inches thick at base	7
3.	Tuff, gray, similar to unit No. 1	4
2.	Tuff, very hard, purplish with white rock and crystal fragments	2
1.	Tuff, gray to white; weathers to a hard nodular gravel. Base covered by alluvium	6
	Total thickness measured.	50



PANORAMA OF NORTHERN BUCK HILL QUADRANGLE

Volcanic succession over 2000 feet thick is shown. Pruett tuff capped by Cottonwood Spring basalt forms lower mesas; Duff tuff capped by Mitchell Mesa rhyolite forms upper mesas. (Photograph by C. L. Baker)

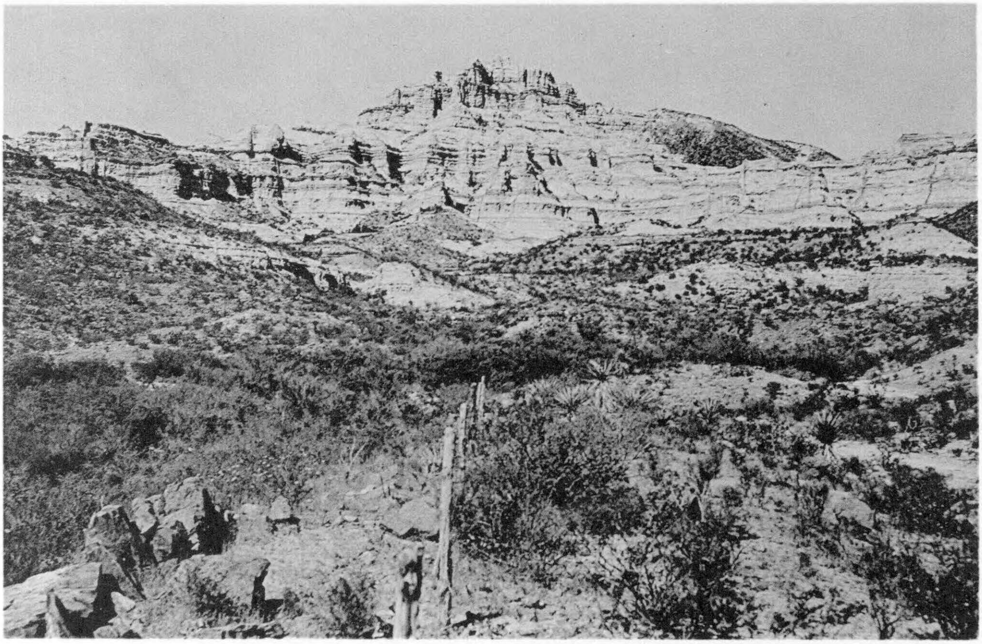


FIGURE 1. DUFF TUFF
Upper part of the Duff tuff in Jordan Gap quadrangle, 6 miles west of Mitchell Mesa.
Clastic dike in left foreground.

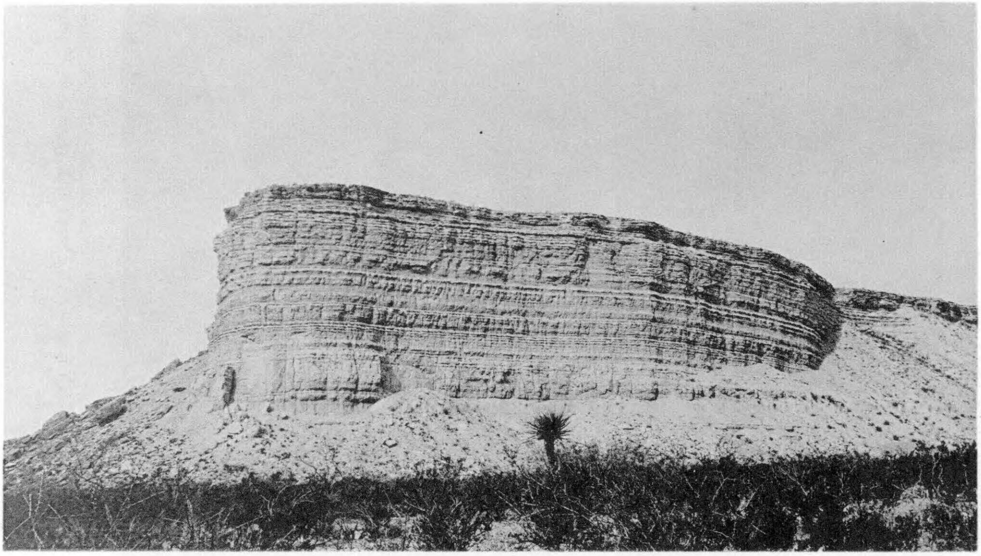


FIGURE 2. PRUETT TUFF
Boat Mountain showing 200 feet of Pruett tuff capped by the upper breccia-conglomerate member.

PRUETT AND DUFF FORMATIONS

The basal conglomerate is well exposed in Hill 3927, 2½ miles northeast of Butcherknife Hill, where it is 6 feet thick and grades up to tuffaceous pebbly sandstone, 15–20 feet thick. Grains of biotite and other dark minerals and fragments of dark chert give the sandstone a speckled appearance. Good exposures of the basal Pruett beds also are found in the vicinity of Butcherknife Hill. On the northwest side of the hill the conglomerate, sandstone, and breccia dip 25° NW. On the east side, the lower part of the section is covered, and the conglomerate is not exposed, but a 10-foot bed of sandstone is included in the calcareous tuff beds. The section follows:

Unit	*Description*	*Thickness in feet*
5.	Interval covered with float of dense basalt exposed at top of Butcherknife Hill. In part, Butcherknife basalt..	77
	Pruett tuff; basal conglomerate member:	
4.	Tuff, containing thin limestone beds and nodules near top grading down to calcareous tuff and sandy tuff at base of interval...........................	17
3.	Sandstone, light gray, very coarse-grained, friable, tuffaceous, and calcareous. (Sample No. 1231).......	10.5
2.	Tuff, gray, sandy..................	5.5
1.	Tuff, red, fine-grained, base covered by float and alluvium..............	2
	Total thickness measured........	112

At Buck Hill the syenite which now caps the hill intruded the lower Pruett beds. The following section was measured on the southeastern side of the hill:

Unit	*Description*	*Thickness in feet*
6.	Syenite to top of hill	
	Pruett formation; basal conglomerate member:	
5.	Tuff, hard red....................	5
4.	Sandstone, calcareous, with layers of tuffaceous limestone...............	10
3.	Conglomerate, limestone pebbles in a calcareous sandstone matrix........	3
	Boquillas limestone:	
2.	Limestone, thin-bedded, fine-grained.	2
1.	Limestone, thin- to thick-bedded, dense, black, with poorly preserved pelecypods. Base covered.........	8
	Total thickness measured........	28

In a large gully south of Bench Mark 4203 on Buck Hill, a short distance west of the locality of the preceding section, 30 feet of the lower Pruett is exposed. The section follows:

Unit	*Description*	*Thickness in feet*
5.	Syenite to top of hill.................	50
	Pruett formation; basal conglomerate member:	
4.	Tuff, red and yellow, fine-grained....	15
3.	Sandstone, tuffaceous, calcareous....	10
2.	Conglomerate and conglomeratic sandstone............................	5
	Boquillas limestone:	
1.	Limestone, massive beds at top with thin, slabby limestone below. Covered at base for 82 feet to Cretaceous limestone flat south of Buck Hill. Thickness including covered part....	126
	Total thickness measured........	206

In the Buck Hill quadrangle the basal conglomerate and sandstone generally do not exceed 15 feet in thickness. The overlying tuff beds are sandy and calcareous and commonly include one or more sandstone layers. Field relations indicate that the beds of sandstone in the tuff at Butcherknife hill and in the small hill south of Crossen Mesa are not many feet above the base of the formation. Accordingly they are included in the basal conglomerate member which is defined to include the conglomerate, sandstone and arkose, and sandy and calcareous tuff in the lower 40–50 feet of the Pruett formation.

Fresh-water limestone.—Massive beds of fresh-water limestone occur in the Pruett formation just below the Crossen trachyte. In Sheep Canyon in the Alpine quadrangle (Pl. 6) these tuffaceous limestone and highly calcareous tuff beds are 300 feet thick in the spur between Sheep Creek and Calamity Creek. The limestone ranges from grayish white to tan and chocolate brown. Much of it is in beds up to 10 feet thick, but locally beds a few inches thick are interbedded with calcareous tuff or are separated by shaly partings. The limestone is fossiliferous, and the silicified gastropods stand out on weathered surfaces. Algal structures are common.

In Sheep Canyon the limestone is overlain by the Crossen trachyte and by the Sheep Canyon basalt where the trachyte has been eroded. In the eastern scarp of the mesa east of Calamity Creek and north of Elephant Mountain, the fresh-water limestone lies both below and above the Crossen trachyte where the latter has been thinned, presumably by erosion. Beds of the tuffaceous limestone, 40 feet thick, are overlain by the Sheep Canyon basalt, and the three lower basalt flows are separated by beds of the fresh-water limestone (Appendix, Section No. 6). The limestone is in part older than the trachyte, and in part its deposition spans the interval of extrusion of the Crossen trachyte and the Sheep Canyon basalt lavas.

Upper breccia-conglomerate.—Tuff breccia and conglomerate in the upper part of the Pruett formation, approximately 60 feet below the Cottonwood Spring basalt, are designated the upper breccia-conglomerate member. It may be a single thick, well-cemented, and coherent layer or it may consist of several layers about 1 foot thick separated by thin beds of coarse tuff. The breccia contains angular fragments of a variety of igneous rocks with some pieces of chert and jasper. Generally the pieces are less than half an inch in greatest dimension and exhibit structures and textures such as spherulitic, eutaxitic, fine-grained dense or vesicular, and porphyritic with small crystals of sanidine and quartz. Some dark-red vesicular fragments suggest basic igneous rocks, but most are silicic. Locally some of the pieces are rounded and attain a foot or more in diameter.

The breccia-conglomerate is cemented with calcareous tuffaceous material and is resistant to erosion forming a bench in the Pruett formation below the basalt-capped hills and mesas west of Whirlwind Spring and north of the 02 ranch road. At Whirlwind Spring the bed, 2–6 feet thick, is composed of angular igneous fragments which generally are less than half an inch across. The layer is much thicker at Boat Mountain where large slabby pieces have slumped off from the caprock ledge and cover the base of the slope. In this slumped material along the road there are more or less rounded igneous boulders as much as 3 feet in diameter. West of Boat Mountain and south of elevation 4054 feet (Appendix, Section No. 5) the breccia-conglomerate is 2–6 feet thick with a considerable range in size of fragments.

Good exposures of the breccia-conglomerate and tuff beds above it are found along Duff Creek in the western part of the quadrangle and can be traced westward into the Jordan Gap quadrangle where the breccia-conglomerate member is as much as 40 feet thick. In the Duff Creek area the member is 2–6 feet thick and is composed of angular to well-rounded pieces many of which are 2–3 inches in diameter. The proportion of fragments to tuff matrix is large. The following section was measured on the west slope of Hill 4325 east of Duff Creek:

Unit	*Description*	*Thickness in feet*
Cotton-wood Spring Basalt:		
8.	Basalt, fine-grained, massive, dark-green	
Pruett formation:		
7.	Tuff, dense, hard, baked, dark-red....	3
6.	Ash, soft, earthy, weathered (?), with no apparent stratification, red.......	30
5.	Tuff, thick-bedded, red with white specks..........................	11
4.	Tuff, coarse, poorly bedded but in thick rough layers, mottled gray and pink............................	7
3.	Tuff, thin-bedded, pink and gray....	11
2.	Upper breccia-conglomerate member, resistant bed of large volcanic fragments in a five-grained red tuff matrix	2
1.	Tuff to base of slope................	
	Total thickness measured.	64

The breccia-conglomerate member was originally extensive, covering many square miles. It caps the Pruett in the faulted block southwest of the Pruett ranch house. A thin bed of breccia with small angular gray to reddish-brown fragments in a porous light-grayish-pink to pink matrix caps 50 feet of tuff on the trachyte in Hill 5202 on Crossen Mesa. This breccia occupies a position below the Cottonwood Spring basalt which stratigraphically is analogous to that of the breccia-conglomerate in the downfaulted area southwest of the mesa and is considered a remnant of the breccia-conglomerate member. Northwest of Hill 5202 on Crossen Mesa the breccia-conglomerate was not found, and its position in the succession is occupied by the Potato Hill andesite flow (Fig. 3).

Composition.—The greater part of the Pruett formation is fine-grained tuff, commonly calcareous, and locally silicified. The lower tuff beds above the basal conglomerate-sandstone member generally are calcareous and commonly contain thin layers and nodules of limestone. Part of the calcium carbonate probably was derived from the erosion of the exposed Cretaceous formations, but a large part probably was precipitated in the lakes and ponded water in which the volcanic ash was deposited. In the northern part of the Buck Hill quadrangle and in the Alpine quadrangle thick beds of fresh-water limestone in the upper part of the formation were deposited in ponds. Abundant algal structures, charophytes, and fossil gastropods suggest that organic processes were important in the accumulation of the limestone. The limestone is tuffaceous and grades to calcareous tuff.

The tuff beds in the uppermost part of the formation generally contain less calcium carbonate than the lower beds. Thin sections show no recognizable glass, but relict structures suggest devitrified shards. Fragments of quartz and feldspar are variable in abundance. A light-gray to cream-colored sample from poorly stratified tuff below the Potato Hill andesite at Hill 4975 on Crossen Mesa was analyzed (Table 2, No. 1). The tuff, 37 feet thick at this locality, is overlain by 40 feet of andesite succeeded by 26 feet of tuff to the base of the Cottonwood Spring basalt (Appendix, Section No. 7), so that the analyzed sample was taken 70 feet below the top of the Pruett formation. The sample is similar to an analyzed sample from the younger Duff tuff of Mitchell Mesa (Table 2, No. 2). Both samples are considerably altered as indicated in the large contents of water. Despite the greater alteration suggested by its larger water content, the Pruett tuff sample has a larger relative amount of lime which in the absence of carbon dioxide suggests that the parent material of the Pruett tuff represented by the analyzed sample probably was more basic than that of the Duff tuff.

Part of the analyzed sample was crushed, and the heavy minerals separated with bromoform (D = 2.86). The heavy-mineral fraction is small and consists principally of magnetite partially altered to hematite and limonite. Chlorite and sphene are the most abundant nonopaque minerals. The chlorite is in small rounded flakes; the sphene commonly shows crystal faces. A few grains of apatite, aegirine-augite, rutile, biotite, muscovite, and zircon were noted. A sample of gray calcareous tuff from below the trachyte in the ravine south of Hill 5202 contains similar heavy minerals, but fresh biotite, zircon, and apatite are relatively more abundant. Very hard, dense, purple, silicified tuff in thin layers about halfway up the southern scarp of Crossen Mesa is composed of shards of silicic volcanic glass with minor quartz and feldspar, a few rock fragments, and a little calcite.

TABLE 2.—*Chemical analyses of samples of tuff from the Pruett and Duff formations*
(S. S. Goldich, analyst)

	1	2
SiO_2	69.73	70.57
Al_2O_3	12.06	12.19
Fe_2O_3	1.06	1.29
FeO	.13	.09
MgO	.88	.60
CaO	2.16	1.43
Na_2O	.78	1.80
K_2O	4.17	5.09
H_2O +	5.05	3.36
H_2O −	3.31	2.84
CO_2	.01	.14
TiO_2	.18	.22
P_2O_5	.04	.08
MnO	.01	.01
BaO	.13	.04
SrO	.09	n.d.
S	.00	.00
	99.79	99.75
Sp. gr.	2.368	2.421

1. Tuff from the Pruett formation below Potato Hill andesite at Hill 4975 on Crossen Mesa. Sp. gr. 24°/4°.
2. Tuff from the Duff formation, approximately 100 feet below Mitchell Mesa rhyolite, Mitchell Mesa. Sp. gr., 26.6°/4°.

The coarser clastic materials of the Pruett formation include conglomerate, breccia, and arkosic sandstone. The basal conglomerate consists chiefly of well-rounded pebbles and cobbles of limestone with more angular pebbles of chert, jasper, and petrified wood. Pebbles of marble and quartzite are common, but igneous rock pieces are rare. The related sandstone contains abundant orthoclase and silicic plagioclase. In addition to the lower beds there are lentils and thin layers of conglomerate and sandstone at higher levels. On the northwest slope of Hill 4140 south of the 02 ranch house a bed of conglomerate 6½ feet thick is overlain by 5 feet of sandstone. The conglomerate is composed of rounded limestone and tuff pebbles. These beds occur in the tuff 70 feet above the base of the hill and 30 feet below the base of the overlying basalt flows which are assigned to the Cottonwood Spring basalt, so that the sandstone and conglomerate are near the top of the Pruett formation. The beds appear to be local and could not be traced in other parts of the hill. Three miles south of Hill 4140 in the bed of Terlingua Creek tuffaceous sandstone is exposed along an east-west fault which is the western extension of the Chalk Draw fault.

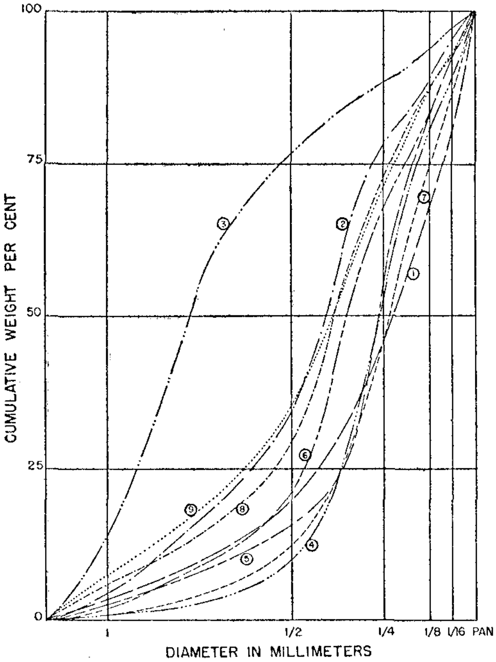


FIGURE 4.—CUMULATIVE CURVES REPRESENTING TEXTURAL ANALYSES OF SANDSTONE SAMPLES FROM THE PRUETT FORMATION

Nine samples of sandstone from the Pruett formation from scattered localities in the quadrangle were treated with dilute hydrochloric acid to dissolve the calcareous cement. The loss in weight in the acid ranged from 26 to 61 per cent. The clay and silt fraction ranges from 1.6 to 4.2 per cent, and the sand fraction from 37 to 71 per cent. Constants for the sand fractions of the samples from cumulative curves (Fig. 4) are given in Table 3. These include the median diameter (Md) and coefficients of sorting (So) and of skewness (Sk). The samples are calcareous sandstones in which the medium to coarse sand is characterized by a high degree of sorting. There is no appreciable difference between sample No. 8 from the upper part of the formation and the samples from the basal conglomerate member. Sample No. S from the southwest slope of Butcherknife Hill is an arkose containing abundant silicic feldspar, quartz, and rock fragments cemented by clear granular calcite. Some dense, darker calcite with sections of Foraminifera and structures suggesting fossil shells appears to be pieces of fragments derived from the Cretaceous limestones. Small fragments of ophitic and trachytic rocks, chert, and chalcedony are minor, and the principal constituents in addition to the calcite and limestone fragments are abundant angular orthoclase, silicic plagioclase, and quartz. Accessory minerals are biotite, muscovite, tourmaline, and a radiating fibrous mineral which may be a zeolite.

Thin sections of the upper breccia-conglomerate from localities south of Cottonwood Spring and in Duff Creek show fragments of spherulitic, eutaxitic, dense, and porphyritic varieties of rhyolite, and trachytic and ophitic volcanics. The ophite consists of minute plagioclase laths in an indeterminable reddish-brown matrix. The fragments are cemented with a selvage of fine-grained material containing grains of quartz and alkalic feldspar.

Stratigraphic relations.—The Pruett formation rests unconformably on the Boquillas formation and is overlain by the Cottonwood Spring basalt. Deposition of the tuff and related sediments was locally interrupted by invasions of lavas which moved into the area from the north. The Crossen trachyte, which rests on tuff and fresh-water limestone of the upper Pruett, was eroded and removed from large areas, so that the younger Sheep Canyon basalt flows came to rest on the fresh-water limestone member and overrode the erosion-thinned trachyte (Fig. 3). A third invasion of porphyritic andesite followed. In the northern part of the quadrangle the basal Cottonwood Spring flow rests on deeply weathered **Potato** Hill andesite or on tuff beds on the andesite, but south of the Walnut Draw fault the basal flow rests on soft, earthy, red ash which probably represents deeply weathered Pruett tuff. Breaks in the deposition of the Pruett, other than those caused by the lavas, are difficult to determine. The upper breccia-conglomerate, 60 feet below the top of the formation, marks a break, the magnitude of which is not known, but in this member is the first appearance of large igneous cobbles and boulders.

TABLE 3.—*Bulk composition and textural constants for samples of sandstone from the Pruett formation*

	Weight per cent								
	1	2	3	4	5	6	7	8	9
Bulk composition:									
Loss in dil. HCl	33.2	59.4	27.8	41.6	40.4	60.8	30.2	26.2	36.0
Clay and silt	1.6	3.4	1.6	4.2	4.0	2.6	6.0	3.0	2.0
Sand	65.2	37.2	70.6	54.2	55.6	36.6	63.8	70.8	62.0
Constants:									
Md (mm.)	0.23	0.41	0.78	0.26	0.26	0.35	0.23	0.38	0.39
So	2.17	1.49	1.32	1.52	1.47	1.56	1.71	1.54	1.70
SK	.79	1.01	.81	.87	.88	.73	.85	.87	.91

1. Above conglomerate in small hill below Crossen Mesa, 1 mile east of Pruett ranch house. Cat. No. 872.
2. Above basal conglomerate, along O2 ranch road, 1¼ miles northeast of Whirlwind Spring. Cat. No. 869.
3. From basal conglomerate member, east side of Butcherknife Hill. Cat. No. 1231.
4. Same as 3, west side of Butcherknife Hill. Cat. No. 830-A.
5. Same as 3, southwest slope of Butcherknife Hill. Cat. No. 831.
6. Above basal conglomerate, along road to Sid Place, southwest side of fault, approximately 2 miles west of Butcherknife Hill. Cat. No. 1232.
7. From bed of Calamity Creek Wash, half a mile northwest of sample No. 6. Cat. No. 1230.
8. Above conglomerate bed, approximately 70 feet above base on northwest slope of hill half a mile south of O2 ranch house. Cat. No. 883.
9. From bed of Terlingua Creek, along fault west of Straddlebug Mountain. Cat. No. 1244.

Crossen Trachyte

Definition and description.—The massive flow of porphyritic trachyte capping Crossen Mesa in the north-central part of the Buck Hill quadrangle is designated the Crossen trachyte. It covers approximately 20 square miles on the mesa (Pl. 1) and also caps extensive areas to the north in the Alpine quadrangle (Pl. 6). The flow came into the Buck Hill region from the north or northwest. No trace of the trachyte is found in Elephant Mountain east of Crossen Mesa, but it may have been removed by erosion. Northwest of Elephant Mountain (Pl. 6) the trachyte was eroded from a large area by an ancient (Eocene?) stream.

The fresh trachyte is hard and brittle with an even to subconchoidal fracture. Abundant stubby phenocrysts of glassy feldspar are evenly distributed in a fine-grained, grayish to reddish-brown groundmass. Near the southern rim of Crossen Mesa the upper part of the flow is vesicular with many fillings of chalcedony. The vesicles are strongly elongated, generally northwest-southeast, accentuating the flow lines and the alignment of the phenocrysts. The vesicular top of the flow locally was broken and recemented to form a prominent flow breccia which is well-exposed in the bed of Goat Creek on the mesa and in Walnut Draw on the western edge of Crossen Mesa,

The present surface of the Crossen trachyte is essentially a dip slope, dipping 1°–2°, N. 20° W., from which erosion has removed much of the brecciated vesicular top. In the cliff on the southern edge of the mesa the trachyte is about 120 feet thick, and a thickness of 115 feet is estimated (Appendix, Section No. 4) in the first gully north of the southeastern tip of the mesa. The flow is considerably thicker to the northwest, averaging 150 feet.

TABLE 4.—*Chemical analysis of Crossen trachyte*

From the upper part of the flow, head of first gully north of the southeastern end of Crossen Mesa

(S. S. Goldich, analyst)

SiO_2	71.17
Al_2O_3	12.64
Fe_2O_3	4.28
FeO	.11
MgO	.13
CaO	1.05
Na_2O	3.91
K_2O	5.05
H_2O +	.23
H_2O −	.12
CO_2	.19
TiO_2	.56
P_2O_5	.07
MnO	.14
BaO	.08
SrO	n.d.
S	tr.
	99.73
Sp. gr. (24°/4°)	2.648

The trachyte weathers to a rusty-brown pitted surface, the pits resulting from the weathering out of the phenocrysts. Some of the weathered rock is bleached to a light yellow or yellowish gray, and as this type is found in place beneath calcareous tuff it may represent ancient (Eocene?) weathering. The vertical jointing of the flow favors the development of vertical walls or cliffs on the edge of the mesa. Marginal fragmentation of the trachyte yields abundant debris that covers the more gentle slopes of the less coherent underlying tuff.

Petrography.—The fine-grained groundmass is not readily resolved even under high magnification. It consists principally of microlites of silicic feldspar with minor amounts of altered ferromagnesian mineral, which originally probably was aegirine-augite, and of magnetite and apatite. Secondary iron oxides and a chloritic mineral are the chief alteration products, and the red color of the rock is derived from the abundant finely disseminated hematite.

The feldspar phenocrysts are rounded and irregularly corroded. They are chiefly anorthoclase with delicately developed quadrille twinning and moderately large 2V. Clear untwinned feldspar with small (-) 2V is sanidine. The phenocrysts are much altered to carbonate, hematite, and a chloritic mineral. These secondary products in part were developed at the expense of original ferromagnesian minerals included in the feldspar phenocrysts. Carbonate pseudomorphs with outlines marked by films of hematite and with small veinlets of hematite suggest original olivine. A few larger grains of the original pyroxene largely altered to a dark-green mineral appear to be aegirine-augite. Grains of granular quartz probably are secondary, and chalcedony was introduced.

Chemical analysis.—The trachyte is characterized by an unusually high silica content of 71 per cent (Table 4), largely as a result of the introduction of secondary quartz and chalcedony. The relatively large content of ferric oxide reflects the oxidation of the iron-bearing minerals to hematite.

Stratigraphic relations.—The Crossen trachyte rests on tuff and fresh-water limestone of the Pruett formation. In the vicinity of Potato Hill it is overlain by tuff beds assigned to the upper part of the Pruett which are succeeded by the Potato Hill andesite. Near the northern boundary of the quadrangle a flow of the Sheep Canyon basalt rests directly on the trachyte, and farther north in the Alpine quadrangle (Hardin, 1942) the trachyte was eroded by an ancient stream, the channel of which subsequently was filled with flows of the Sheep Canyon basalt. Small hills or erosional remnants of the Crossen trachyte were surrounded by the flows, and these now appear as inliers in the Sheep Canyon basalt (Pl. 6). The stratigraphic relationships of the

Crossen trachyte, the Pruett beds, and the Sheep Canyon basalt flows are shown schematically in Figure 3.

Sheep Canyon Basalt

Definition and description.—Basalt flows intercalated with fresh-water limestone and tuff beds of the Pruett formation are referred to the Sheep Canyon basalt. These are younger than the Crossen trachyte and older than the Potato Hill andesite. The flows are named for Sheep Canyon, a re-entrant of Calamity Creek valley in the Alpine quadrangle approximately 3 miles north of the Buck Hill quadrangle (Pl. 6).

The Sheep Canyon flows originally were extensive in the northern part of the Buck Hill quadrangle but have been eroded from large areas. The basalt is now found on Crossen Mesa and in the downfaulted block southwest of the mesa. The southernmost outcrop of the flows is along an east-west fault approximately 1 mile south of the Pruett ranch house. The flows cover large areas in the Alpine quadrangle where they are much thicker. In Sheep Canyon at least four flows are separated by thin beds of tuff and tuffaceous limestone.

The basalt typically is dark greenish black, even-textured, fine- to medium-grained, locally containing large, glassy, green plagioclase phenocrysts, many of which are 1 inch long. On relatively steep slopes the basalt commonly develops a platy structure on weathering; on gentle slopes and in the bottoms of gullies spheroidal structures result. The vesicular tops of the flows contain abundant fillings of quartz, chalcedony, and calcite and commonly are a distinctive green. In many places small flats and benches are developed at the contact of two flows.

At the type locality in Sheep Canyon in the section measured by Hardin (Appendix, Section No. 6), the basalt flows are 234 feet thick. The upper basalt flow in this section is overlain directly by the Potato Hill andesite, but on Crossen Mesa in the Buck Hill quadrangle a thickness of 20 feet or more of tuff separates the Sheep Canyon basalt from the Potato Hill andesite. A section measured on a little hill north of Potato Hill and just south of the northern boundary of the quadrangle follows:

Unit	*Description*	*Thickness in feet*
	Pruett formation:	
4.	*Potato Hill andesite intercalation*	
3.	Tuff, gray, well stratified, interbedded with purplish-red ash speckled with white fragments; upper 2/3 feet baked, dense, red tuff....................	27
2.	*Sheep Canyon basalt intercalations:*	
	b. Basalt flow, black fine-grained rock with vesicular top altered green; weathers to flattish biscuitlike forms. Red baked ash included in thin flow breccia at base of flow..................	34
	a. Basalt flow, uniform black, fairly coarse-grained but not porphyritic. Well-developed vesicular top...........................	21
1.	*Crossen trachyte intercalation:* Red porphyritic trachyte breccia............	
	Total thickness measured.	82

Half a mile south of this hill the upper flow only is present. It is 27 feet thick, coarse-grained and porphyritic. The vesicular base of the flow rests on baked, dense, red tuff grading down to well-stratified gray tuff resting on trachyte breccia. The tuff is 13 feet thick. The green vesicular top of the basalt flow is overlain by stratified gray ash capping the low hill. To the west this ash is overlain by the Potato Hill andesite. East of Goat Creek and southwest of elevation 5016 feet, the Sheep Canyon basalt is intercalated with ash resting on the Crossen trachyte. At this point the basalt is 30 feet thick but feathers out to the southeast, and on the southern scarp below elevation 4975 feet no trace of the Sheep Canyon basalt is found.

In the spur west of Goat Creek two flows of the Sheep Canyon basalt rest on 11 feet of tuff and are overlain by 20 feet of tuff beneath the Potato Hill andesite. The flows are of equal thickness, totaling 65 feet, and have well-developed vesicular tops. A prominent flat or bench on the southeastern end of the spur roughly marks the top of the first flow.

South of Crossen Mesa the Sheep Canyon basalt is exposed in gullies in an area approximately 1 mile square. This area is bounded on the east and south by the Cottonwood Spring basalt which is downfaulted against the Pruett tuff. At this locality a flow 30 feet thick lies in well-stratified, grayish-white tuff. The top is amygdaloidal with many fillings of chalcedony and calcite. The flow was weathered following extrusion of the lava, and fragments of weathered vesicular basalt are contained in the overlying gray tuff which grades upward to pink and grayish-white stratified volcanic ash. Narrow (2-inch) veins of massive aragonite cut the basalt.

TABLE 5.—*Chemical analyses of Sheep Canyon basalt from Buck Hill and Alpine quadrangles*
(S. S. Goldich, analyst)

	1	2	3
SiO_2	44.33	45.65	45.97
Al_2O_3	14.69	16.48	17.26
Fe_2O_3	4.27	6.92	2.84
FeO	8.68	6.40	9.18
MgO	4.88	4.05	5.63
CaO	7.00	7.48	7.87
Na_2O	3.46	3.38	4.33
K_2O	2.15	1.42	1.00
H_2O +	2.15	2.10	1.57
H_2O −	1.09	1.39	.20
CO_2	.07	.37	.00
TiO_2	3.64	3.21	2.87
P_2O_5	2.99	.87	.96
MnO	.23	.18	.17
BaO	.17	.09	.07
SrO	.14	.09	.10
S	.00	.00	.00
	99.94	100.08	100.02
Sp. gr.	2.818	2.829	2.874

1. Basalt flow in gully, 1450 feet N. 48° W. of Hill 4321′, south of Crossen Mesa. Cat. No. 841. Sp. gr, 25.274°.
2. Porphyritic basalt, upper of two flows on Crossen Mesa, 1 mile north of Potato Hill. Cat. No. 832. Sp. gr, 25.8°/4°.
3. Porphyritic basalt in gully, east side of Elephant Mountain, Alpine quadrangle; 100 feet below base of syenite. Cat. No. E. M. 14. Sp. gr., 22°/4° (See Pl. 6).

Petrography.—In Sheep Canyon the basalt flows are rather uniform both in texture and in composition. The groundmass is dominantly feldspathic and distinctly diabasic. The plagioclase is labradorite (An_{55}), and the large crystals commonly are zoned with cores as calcic as An_{60}. Zonal inclusions of magnetite and pyroxene in the feldspar phenocrysts are common. Augite, olivine, and magnetite are the other essential primary minerals, and apatite is the chief accessory mineral. Olivine occurs in about equal amounts in all the flows. Hardin (1942) estimates the composition of the olivine from measurements of the optic angle to be approximately Fo_{70} Fa_{30}. The olivine is considerably altered to antigorite which shows the polygonal outline of the olivine crystals, but there are some residual olivine grains. The amount of augite is variable. Magnetite is abundant—10–15 per cent of the rock. Analcime, calcite, sericite, fibrous zeolites, and clay minerals occur in varying amounts.

Thin sections of the basalt from the Buck Hill quadrangle show the rock to be generally similar to the flows in Sheep Canyon, but a few special features are worthy of mention. Samples of the flows north of Potato Hill show zoning in the plagioclase which is the reverse of the normal zoning described above, and rounded central zones are more sodic than the outer ones. The zones commonly are marked by lines of euhedral crystals of magnetite. A silicic feldspar, probably orthoclase, in the groundmass is interstitial and marginal to the plagioclase. The serpentinous alteration products of olivine include olive-green fibrous material and a reddish-brown flaky mineral, probably bowlingite. Calcite is an abundant secondary mineral. The pyroxene is distinctly purplish and pleochroic indicating a titaniferous augite. Samples of greenish-gray basalt collected southwest of Hill 5106 feet are fine- to medium-grained with a diabasic to granular texture. Feldspar makes up 70 per cent or more of the rock. Olivine and its alteration products do not exceed 5 per cent of the rock, and pyroxene, 10–15 per cent. The abundance of silicic feldspar is striking, and the rock is more nearly a latite than basalt.

The basalt in the downfaulted block south of Crossen Mesa resembles the flows north of Potato Hill. Analcime is not abundant. Apatite is exceedingly abundant in small prismatic crystals.

Chemical analysis.—Three analyses of samples of the Sheep Canyon basalt (Table 5) are similar, but in relative abundance of minor constituents, P_2O_5, MnO, BaO, and SrO, the

Elephant Mountain porphyritic basalt more closely resembles the porphyritic basalt sampled north of Potato Hill on Crossen Mesa. The large percentage of titania in the analyzed samples is noteworthy.

Potato Hill Andesite

Definition and description.—The Potato Hill andesite, named for Potato Hill on Crossen Mesa, is a dark reddish-brown porphyritic flow and flow breccia in the upper part of the Pruett tuff. The andesite caps a small hill 500 feet southeast of Potato Hill. Northwest of Potato Hill the flow makes a narrow ridge, and its outcrop continues to the northern boundary of the quadrangle on either side of the basalt-capped hills that crown Crossen Mesa. The andesite is exposed in the spur between Goat Creek and Walnut Draw and in the faulted blocks which make Walnut Draw graben on the western edge of Crossen Mesa, but apparently the flow did not extend beyond the southern . limit of the Crossen trachyte, because it is not found in the downfaulted block south of the Walnut Draw fault zone.

The Potato Hill andesite is easily recognized by its color and prominent plagioclase phenocrysts. The tabular crystals, up to 1 inch in length, are fresh and glassy. They are contained in a fine-grained, reddish-brown groundmass or in a coarser granular grayish-brown matrix. Locally the andesite is altered to a greenish color. The lower part of the flow, although vesicular, is massive; the upper half is a flow breccia. Amygdules of quartz, chalcedony, and calcite are abundant. The upper brecciated part weathers more readily than the massive andesite, and small flats are developed at the change of structure in the flow. The flow was deeply weathered after extrusion and before the succeeding ash was deposited.

At Potato Hill the andesite is 31 feet thick. It lies on approximately 50 feet of tuff which rests on the Crossen trachyte. The andesite is overlain by 25 feet of hard, dense, red tuff. Below elevation 4806 feet, 6000 feet north of Potato Hill, the andesite is only 18 feet thick. It is overlain by 29 feet of well-stratified tuff below the Cottonwood Spring basalt. The relative thinness of the andesite at this point may be the result of weathering rather than original thinning of the flow because in the Alpine quadrangle the andesite is up to 70 feet thick with appreciable flow breccia. In a measured section (Appendix, Section No. 7) in Hill 4975, 1½ miles northwest of Potato Hill the andesite is 40 feet thick, and this thickness holds fairly constant to the northwest. In the spur on Crossen Mesa between Goat Creek and Walnut Draw a small bench or flat marks the break between the massive and brecciated phases of the andesite. The section measured on the southeastern end of the spur follows:

Unit	*Description*	*Thickness in feet*
	Cottonwood Spring basalt:	
7.	Basalt flow; fine-grained, jointed; weathers to reddish-brown slabs. To top of hill..........................	44
	Pruett formation	
6.	Tuff; red, fine- to medium-grained, grading down to weathered andesite, contact approximate................	10
5.	*Potato Hill andesite intercalation:* dark reddish-brown vesicular andesite porphyry in lower 25 feet; flow breccia, much weathered in upper 20 feet....	45
4.	Tuff; gray to red, fine- to medium-grained..........................	20
3.	*Sheep Canyon basalt intercalations:*	
	b. Fine-grained, dark basalt flow with vesicular top...........	32
	a. Fine-grained basalt flow with vesicular top................	33
2.	Tuff, gray, fine- to medium-grained..	11
1.	*Crossen trachyte intercalation:* porphyritic trachyte flow breccia, base of section.............................	
	Total thickness measured.	195

In Walnut Draw graben the brecciated phase is well exposed in the bed of the creek and in a fault slice that hangs on the trachyte forming the east wall of the graben. In this exposure 15–20 feet of andesite breccia is overlain by weathered andesite grading up to tuff which is overlain by the basal flow of the Cottonwood Spring basalt (Pl. 5, fig. 1).

Petrography.—Fine-grained hematite developed by oxidation of the primary ferromagnesian minerals obscures the minerals in the groundmass. The chief mineral is andesine in small lathlike crystals, but there are smaller amounts of a more silicic feldspar, apatite, and magnetite-ilmenite. The large rounded and corroded phenocrysts form about 12 per cent of the rock. They are zoned and range from An_{55}, in inner parts to An_{45} in the outer zones.

TABLE 6.—*Chemical analysis of Potato Hill andesite*
From Hill 4975 on Crossen Mesa
(S. S. Goldich, analyst)

SiO_2	61.46
Al_2O_3	14.85
Fe_2O_3	7.23
FeO	.68
MgO	.74
CaO	5.23
Na_2O	3.75
K_2O	2.58
H_2O +	.22
H_2O −	.17
CO_2	.10
TiO_2	1.52
P_2O_5	1.13
MnO	.11
BaO	.18
S	.00
	99.95
Sp. gr. (24°/4°)	2.764

A large amount of secondary silica occurs as granular quartz filling vesicles and as fibrous chalcedony lining the walls of the cavities. Associated with the quartz and chalcedony is a fibrous mineral, probably celadonite, characterized by strong pleochroism—light yellow parallel to the length of the fibers and blue green at right angles. The brecciated andesite is similar in composition to the massive phase but is cemented with silica or calcite.

Chemical analysis.—The analyzed specimen (Table 6), from a point 1.4 miles northwest of Potato Hill, represents the lower massive phase of the porphyritic andesite. The high silica content reflects the large amount of introduced quartz and chalcedony, and the calculated quartz is 21 per cent of the norm (Table 10). The oxidation of the rock is revealed in the large percentage of ferric iron, and hematite is 7 per cent of the norm. Apatite is 2,7 per cent of the normative minerals. In other respects the analysis is not unusual.

Stratigraphic relations.—The Potato Hill andesite, like the Crossen trachyte and the Sheep Canyon basalt, is an intercalation in the Pruett tuff. The flow was weathered before being covered with volcanic ash, and as a result the contact between the andesite and the overlying tuff is not sharp. This tuff ranges from a few feet to 30 feet thick and is not differentiated on the geologic map (Pl. 1) which shows the Cottonwood Spring basalt resting on the Potato Hill andesite.

Cottonwood Spring Basalt

Definition and description.—The basalt flows lying on the Pruett formation and overlain by the Duff tuff are named for Cottonwood Spring which issues from the base of the flows in a deep gulch cut into the basalt-capped mesa south of Mitchell and Crossen mesas and north of the 02 ranch road. In this area the Cottonwood Spring basalt covers about 17 square miles. The flows continue westward in the Jordan Gap quadrangle where they cover a somewhat smaller area. Remnants of the flows cap small hills north and south of the 02 ranch house along the western boundary of the quadrangle. The basalt dips about 2° to the northwest passing under the Duff tuff, but in the northern part of the quadrangle, on the upthrown side of the Walnut Draw fault zone, the flows cap the hills that rise above the Crossen trachyte and occur in the fault blocks on the western edge of Crossen Mesa. Originally the Cottonwood Spring basalt formed a sheet covering a large part of the quadrangle and adjacent regions to the north and west.

The number of flows varies, and little significance is attached to this feature. Locally small fronts apparently pushed out ahead of the main body of lava to be overridden later. The lower parts of the flows commonly are flow breccias; the upper parts are vesicular and amygdaloidal with numerous fillings of quartz, chalcedony, jasper, and calcite. Large crystals of calcite showing unusual crystal forms and the rarely developed basal pinacoid were collected from cavities in the flows on the hill south of the 02 ranch house, but the crystal faces are etched and are not suitable for measurement. Pahoehoe or ropy lava is found in many places. The massive dense phase of the basalt is grayish black to dark greenish black; the vesicular rock commonly is reddish gray to reddish brown. The flow breccia usually is composed of dense black to fine-grained vesicular basalt. Weathering apparently is controlled by topography. In gullies, low places, and on gentle slopes spheroidal forms develop; whereas on steep slopes and in cliffs a thin slabby structure results. The weathered basalt favors the growth of ocotillo.

The Cottonwood Spring basalt flows are thickest in the hills and mesas west of Whirlwind Spring where a maximum of 325 feet was measured. The original thickness is not known because in this area the Duff tuff has been stripped. The flows are divided into lower and upper units by a thin bed of tuff. The lower unit comprises two to six flows, totaling 100–150 feet. The upper unit in most places is a single massive flow or remnant of a thick flow which southwest of Cottonwood Spring is 164 feet thick, but in other places this thickness may represent five or more flows. The tuff bed breaking the succession of Cottonwood Spring basalt is 1–19 feet thick. Generally it is less than 5 feet thick and is baked, hard, dense, red rock. In thicker beds the tuff away from the contacts is gray and less indurated. Locally rounded fragments of vesicular basalt are contained in the lower part of the tuff bed, and in places the tuff was fragmented and incorporated in the base of the overriding flow.

In the type section (Appendix, Section No. 5) measured up the south point of the basalt mesa southwest of Cottonwood Spring the flows aggregate 300 feet. The lowermost flow resting on red tuff of the Pruett formation is 40–50 feet thick. The contact is marked by a resistant ledge, 3–4 feet thick, of coarse-grained basalt. The upper 9 feet is vesicular with many fillings of quartz, chalcedony, agate, and calcite. Four flows ranging from 6 to 15 feet thick and one 50 feet thick complete the lower unit of 130 feet of basalt in six flows beneath a tuff bed, 8–19 feet thick. Above the tuff is 164 feet of basalt, apparently a single thick flow with a prominent flow breccia of vesicular basalt at the base and a 20-foot amygdaloidal top. This flow caps the mesa and makes cliffs 60 to 80 feet high on the southern scarp. The thickness of amygdaloid suggests that erosion has not removed much of the flow, but younger flows probably were eroded, and the original thickness may have been greater than the 300 feet of basalt measured.

A good section of the Cottonwood Spring basalt is exposed on Hill 4631 (Fig. 6) 1½ miles northeast of Cottonwood Spring where nine flows are 300 feet thick. The lower part of the section beneath a 7-foot layer of red tuff is 154 feet thick and consists of four flows of which the lower one makes up 83 feet. Above the tuff are five flows which aggregate 148 feet. Southwest of Hill 4321 in the spur at Whirlwind Spring a similar succession of basalt flows with separating tuff bed is 325 feet thick.

At Potato Hill on Crossen Mesa the basal Cottonwood Spring flow is 85 feet thick; a total thickness of 166 feet includes six flows to the top of the hill. North of Potato Hill in Hill 4806, only 67 feet of the basal flow remains. In Hill 4975 (Fig. 6) there are six flows. Five flows beneath a 7-foot tuff bed total 110 feet of which the basal flow makes up 61 feet. The remnant of a thick flow above the tuff is 55 feet thick making the succession, including the tuff, 172 feet in total thickness, The upper flow of Hill 4975 also caps Hill 5016 three-fourths of a mile to the northwest where 135 feet of this flow remains. Immediately below is a dense red tuff, 8 feet thick, which is underlain by 92 feet of basalt in two flows. The total thickness of 235 feet is the maximum measured for the Cottonwood Spring basalt in the northern part of the quadrangle.

In Walnut Draw graben the Cottonwood Spring flows are overlain by the Duff tuff. On the south slope of the elongated hill in the graben 175 feet of basalt was measured, and on the basis of amygdaloidal tops there are seven flows below a thin layer of red tuff. Above the tuff is 80 feet of basalt which caps the hill and forms prominent cliffs. The base of the section is covered by alluvium, but a short distance to the south the Potato Hill andesite is exposed in the bed of Walnut Draw.

Petrography.—Thin sections show a range in composition from trachyandesite or latite to olivine basalt, but no detailed studies of variations between or within the flows have been made. The flows typically are fine- to medium-grained, ophitic to diabasic, uniform and nonporphyritic or with few small phenocrysts. Flow structure, fractured and broken crystals, and wavy extinction are characteristic. Some of the reddish-brown flows are highly oxidized, and the original ferromagnesian minerals including much of the magnetite have been altered to or obscured by hematite. Other secondary minerals are analcime, serpentine, uralitic amphibole, chlorite, and calcite.

TABLE 7.—*Chemical analyses of the basal flow of the Cottonwood Spring basalt, Butcherknife basalt, and similar rocks*

	1	2	3	4	5	6
SiO_2	46.90	48.08	48.53	49.80	46.87	44.81
Al_2O_3	15.82	15.87	17.42	18.38	17.04	16.81
Fe_2O_3	4.18	3.74	3.46	1.84	3.12	4.06
FeO	7.74	7.49	7.48	7.57	6.81	7.19
MgO	4.48	3.86	3.10	2.63	3.35	4.21
CaO	6.24	5.76	6.60	7.09	7.66	7.21
Na_2O	3.80	4.50	5.13	4.94	5.13	4.65
K_2O	2.32	2.43	2.38	2.60	2.39	1.97
H_2O +	1.93	2.17	1.68	1.73	2.99	3.70
H_2O −	1.13	.97	.26	.27	.21	1.07
CO_2	.02	.02	.02	—	—	—
TiO_2	2.79	2.68	2.53	2.30	2.96	3.27
P_2O_5	1.97	1.81	1.10	.95	.93	1.04
MnO	.21	.23	.21	—	.19	—
BaO	.23	.12	.06	—	—	—
SrO	.10	.09	.13	—	—	—
S	.00	.00	.01	—	—	—
	99.86	99.82	100.10	100.10	99.65	99.99
Sp. gr.	2.823	2.762	2.808			

1. Cottonwood Spring basalt, basal flow at Potato Hill on Crossen Mesa. Cat. No. 817. Sp. gr., 26°/4°.
2. Cottonwood Spring basalt, basal flow, three-fourths of a mile southwest of Cottonwood Spring. Cat. No. 840. Sp. gr., 24.5°/4°.
3. Basalt at Butcherknife Hill. Cat. No. 830. Sp. gr., 23.4°/4°.
4. Analcite trachybasalt porphyry, Mountain 3513, Terlingua-Solitario region, Texas.
5. Analcite syenogabbro, Cigar Mountain, Terlingua-Solitario region.
6. Analcite trachydolerite, 1 mile northeast of Mountain 3513, Terlingua-Solitario region.

Nos. 1, 2, and 3, S. S. Goldich, analyst.
Nos. 4, 5, and 6, R. B. Ellestad, analyst (Lonsdale, 1940, p. 1620).

Thin sections of the analyzed specimen (Table 7, No. 2) from the basal flow at the type locality southwest of Cottonwood Spring contain 60–70 per cent of labradorite. The plagioclase, rarely showing well-developed twinning bands, is zoned and commonly has a mantle of orthoclase. Orthoclase also occurs in clear fresh grains together with granular aggregates of analcime interstitial to the plagioclase laths. Olivine, 20–25 per cent of the rock, is largely altered to serpentinous products that penetrate the near-by fractured grains of plagioclase. Pale-green fibrous chrysotile with weak birefringence, and dark-green to yellow and brown iddingsite or bowlingite with stronger birefringence, good cleavage, and marked pleochroism are common. Pyroxene rarely exceeds 10 per cent of the rock and is normal augite, some with a purplish tinge. Most of the augite is fresh, but some is altered to long slender needles of actinolite and to chlorite. Magnetite and apatite are abundant.

Analcime occurs in minor amounts in clear grains between the labradorite laths and in dusty granular aggregates replacing the plagioclase. Its abundance is difficult to estimate, about 5 per cent of the rock. Likewise orthoclase is in sufficient amount to justify modification of the field name basalt, and the analyzed specimen is classified as analcime trachybasalt following the usage of Lonsdale (1940) for similar rocks in the Terlingua-Solitario region to the south.

Chemical analysis.—Analyses (Table 7) of samples of the basal flow of the Cottonwood Spring basalt from Potato Hill and from near Cottonwood Spring are similar in most respects. The samples also resemble analysis No. 3 of the dense basalt from Butcherknife Hill and the analyzed analcime-bearing rocks from the Terlingua-Solitario region (Lonsdale, 1940, p. 1620). There are minor differences between the analyzed samples of the Cottonwood Spring basalt and the Sheep Canyon basalt flows (Table S), but it is not likely that the two groups of flows can be separated by chemical analyses of scattered samples. Selected samples probably would show a greater chemical diversity within each group than between them.

Stratigraphic relations.—On Crossen Mesa the Cottonwood Spring basalt rests on tuff deposited on the weathered surface of the Potato Hill andesite. The tuff at Potato Hill is 25 feet thick, and the fossil soil on the andesite is thin; elsewhere the tuff is thin and the weathered zone is as much as 20 feet thick. The weathered andesite grades upward to red tuff baked to a dense hard rock at the time of extrusion of the basal Cottonwood Spring flow. South of Crossen Mesa beyond the southern limit of the andesite, the Cottonwood Spring basalt rests on the Pruett tuff which immediately below the basal flow is a hard red rock, but below this baked layer is 30 feet of soft, earthy, red material which probably represents tuff weathered contemporaneously with the andesite.

The Cottonwood Spring flows were partly eroded before deposition of the Duff tuff, and in part this erosion accounts for the thinning of the flows from a thickness of over 300 feet near Whirlwind Spring to less than 50 feet 10 miles west in the Jordan Gap quadrangle. The flows are variable in number and in thickness, but both on Crossen Mesa and in the basalt mesa to the southwest the basal flow is relatively thick, 43–85 feet. In both areas the succession of flows with included tuff bed is similar, and there is little doubt that the flows are the same and that they were originally poured out on a relatively flat and probably weathered surface of the Pruett tuff (Figs. 3, 6).

Duff Formation

Definition and description.—The Duff formation, named for Duff Springs in the northwestern part of the Buck Hill quadrangle, is chiefly rhyolitic tuff with minor breccia and conglomerate. The tuff lies on the Cottonwood Spring basalt and is overlain by the Mitchell Mesa rhyolite. In addition to the outcrops in the Mitchell Mesa area there are two small outcrops on the small elongated hill south of the 02 ranch house. The Duff formation covers most of the Jordan Gap quadrangle to the west.

The Duff tuff is predominantly light gray and in strong sunlight is dazzling white in contrast to the darker color of the flows and the duller somber hues of the Pruett tuff. Light shades of red and yellow are common, and alternations of colors give some of the Duff a variegated appearance. Most of the material is fine-grained, well-indurated ash grading locally to tuff-breccia and breccia-conglomerate. Much of the tuff is massive; some is cross-bedded; and a large part is well stratified, ranging from thin laminations to beds 2–6 inches thick, but beds 1 foot or more thick are common. The tuff weathers to chalk-white nodular forms, and the gentler slopes are strewn with pellets and small rounded pebbles of the tuff.

Lenticular beds of conglomerate which generally do not persist for any great distance occur throughout the formation, but probably are more numerous in the lower part. Conglomerate beds are fairly persistent at two levels, however. The lower level is approximately 40 feet above the base of the formation; the upper level is 200–250 feet below the top. These conglomerate beds attain 40 feet in thickness and are characterized by cross-bedding and channeling. They are generally dark brown and stand out in the light-gray tuff.

The Duff formation is 1015 feet thick in the type section measured from the outcrop of the Cotton wood Spring basalt 1½ miles northwest of Duff Springs up a large gully on the southern slope of Mitchell Mesa to the rhyolite caprock. Along the line of section the lower conglomerate, 6 feet thick, is 37 feet above the base of the formation. Two beds of conglomerate near the top of the formation are separated by 46 feet of tuff. The lower bed with igneous boulders 1 foot or more in diameter is 8 feet thick; the upper bed consisting mainly of pebbles and cobbles is 10 feet thick and is 200 feet below the base of the Mitchell Mesa rhyolite. Graham (1942) measured the Duff formation at Whirlwind Mesa in the Jordan Gap quadrangle, approximately 4 miles west of Mitchell Mesa. At this locality the Cottonwood Spring basalt is covered by alluvium, but, including the lower conglomerate which is exposed, the Duff section is 1020 feet thick. The lower conglomerate is 31 feet thick, and an upper single bed of conglomerate, 250 feet below the top of the formation, is 38 feet thick. Allowing 40 feet for the covered interval below the conglomerate at the base of the section, the total thickness of the Duff formation is 1060 feet. At McKinney Mountain 10 miles south of the Whirlwind Mesa section, Graham (1942) measured a thickness of 1400 feet for the Duff formation. The tuff was deposited on an irregular, eroded surface of the Cottonwood Spring basalt, and a variable thickness is expected. The maximum thickness may exceed the measured thickness at McKinney Mountain.

Numerous dikelike masses cut the Duff tuff. These are clastic dikes composed of indurated clay or brecciated tuff, and slickensides and brecciated textures indicate that they are the result of small movements probably related to the faulting. Water moving along the brecciated zones deposited crystals of analcime and calcite in fractures. The clastic dikes are generally vertical or at high angles, and because they are more resistant than the normal tuff erosion leaves wall-like remnants or natural stone fences (Pl. 3, fig. 1).

Composition.—Unlike the Pruett tuff, the Duff rarely is calcareous. A small amount of calcite commonly is found near the clastic dikes and appears to be related to water movement along the dikes. The analyzed sample (Table 2, No. 2) of the Duff tuff is a well-indurated, light-gray, fine-grained, rhyolitic ash in which numerous small flakes of biotite are recognizable with a hand lens. The sample was collected from the east scarp of Mitchell Mesa 100 feet below the top of the formation. In most respects the analysis of the Duff sample is similar to that of the Pruett tuff, but its relative content of alkalies is somewhat greater, and its percentage of lime is considerably less. The Duff tuff, like the Mitchell Mesa rhyolite (Table 8, No. 1), is potassic.

The rhyolitic composition of the tuff also is revealed in petrographic studies of 18 samples collected by Graham (1942) from the formation at McKinney Mountain. The index of refraction of the volcanic glass in samples fairly regularly spaced from bottom to the top of the formation is 1.492 ± .003, indicating a silica content of approximately 73 per cent. Heavy-liquid separations made on pulverized samples, from which the very fine material was removed by washing, yielded uniformly small fractions of heavy minerals, rarely as much as 0.5 per cent by weight of the washed sample. The light fractions, in addition to volcanic glass and its alteration products, contained abundant feldspar and quartz. Magnetite-ilmenite and alteration products are the chief heavy minerals. Biotite is the most abundant nonopaque mineral and occurs in all samples. There are two varieties of biotite. One displays a yellowish-green to dark olive-green pleochroism; the other is a deep reddish-brown variety. Apatite and zircon follow in order of abundance. The apatite is chiefly in subrounded grains, the zircon in well-formed crystals. No variation in relative abundance of biotite, apatite, or zircon with stratigraphic position was found. Less important than these minerals both in relative abundance and in frequency of occurrence are aegirine-augite, hornblende, basaltic hornblende, epidote, sphene, rutile, and muscovite. Aegirine-augite is rare in the samples from the lower half of the formation but appears to be common in the upper part. It is abundant in well-rounded grains in a sample taken near the top of the section.

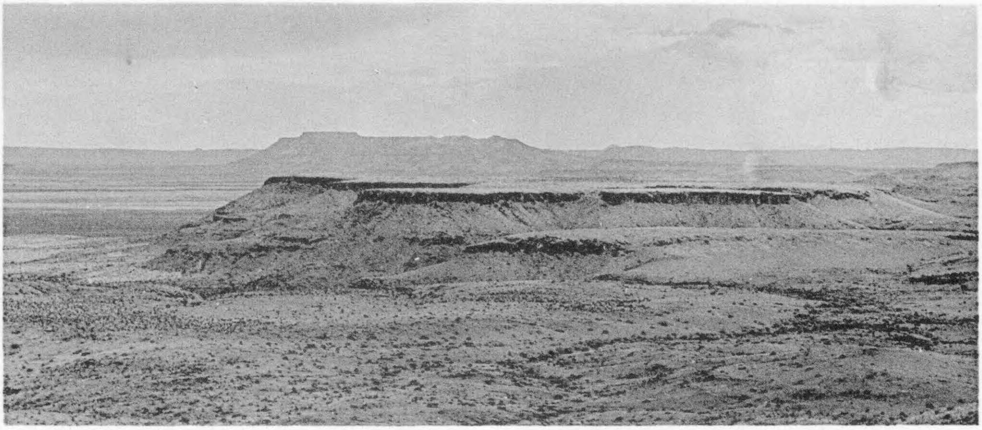


FIGURE 1. LARGE MESA CAPPED BY COTTONWOOD SPRING BASALT
Southwest of Cottonwood Spring. Flat-topped McKinney Mountain, Jordan Gap quadrangle, in distance.

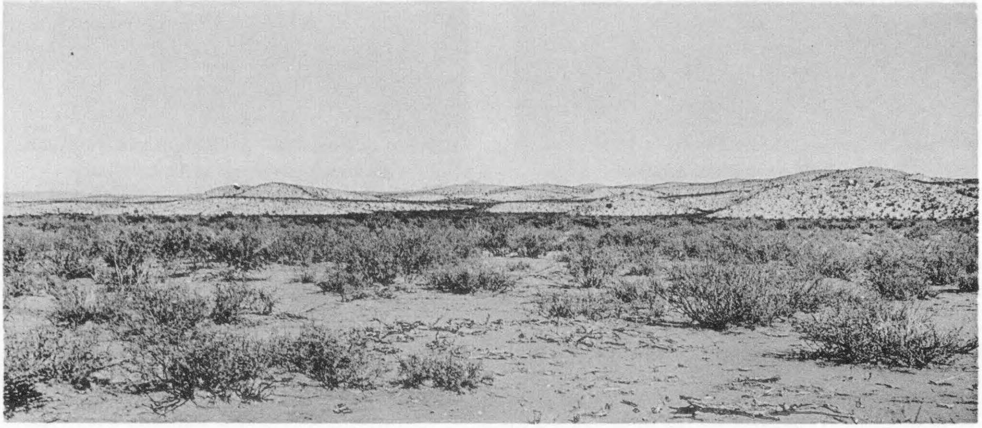


FIGURE 2. UPPER CRETACEOUS BOQUILLAS FORMATION
Rounded hills of the Boquillas formation south of Elephant Mountain.

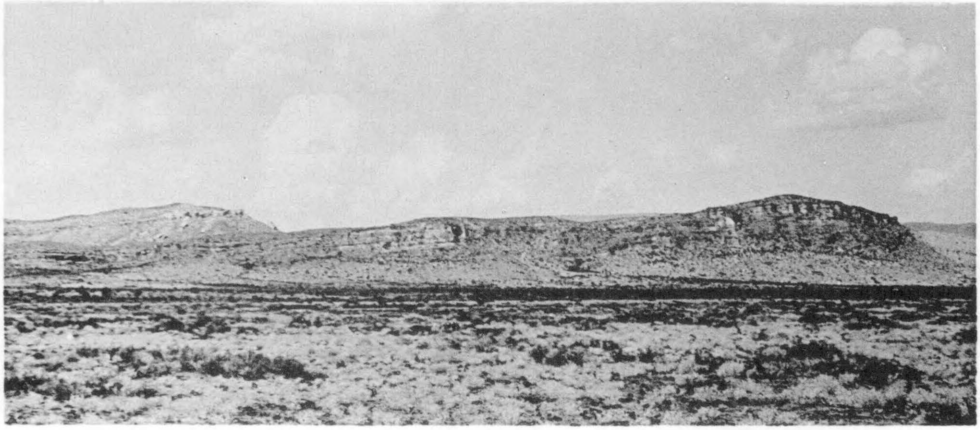


FIGURE 3. LOWER CRETACEOUS FORMATIONS
The lower scarp on the right is formed by the Georgetown limestone; upper scarp on the left, by the Grayson clay overlain by the Buda limestone. (Agua Fria quadrangle).

COTTONWOOD SPRING BASALT AND CRETACEOUS FORMATIONS

FIGURE 1. POTATO HILL ANDESITE
Deeply weathered andesite breccia in Walnut Draw; man is standing on contact of Cottonwood Spring basalt with tuff bed on the andesite.

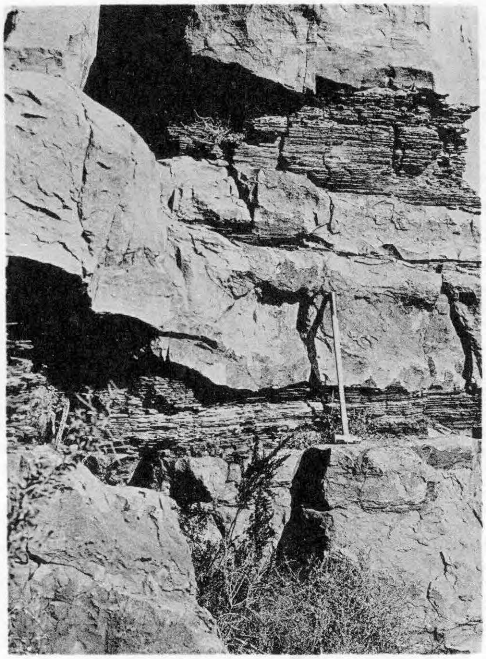


FIGURE 2. SYENITE AT BUCK HILL
Inclusions of thin-bedded Boquillas limestone in syenite.

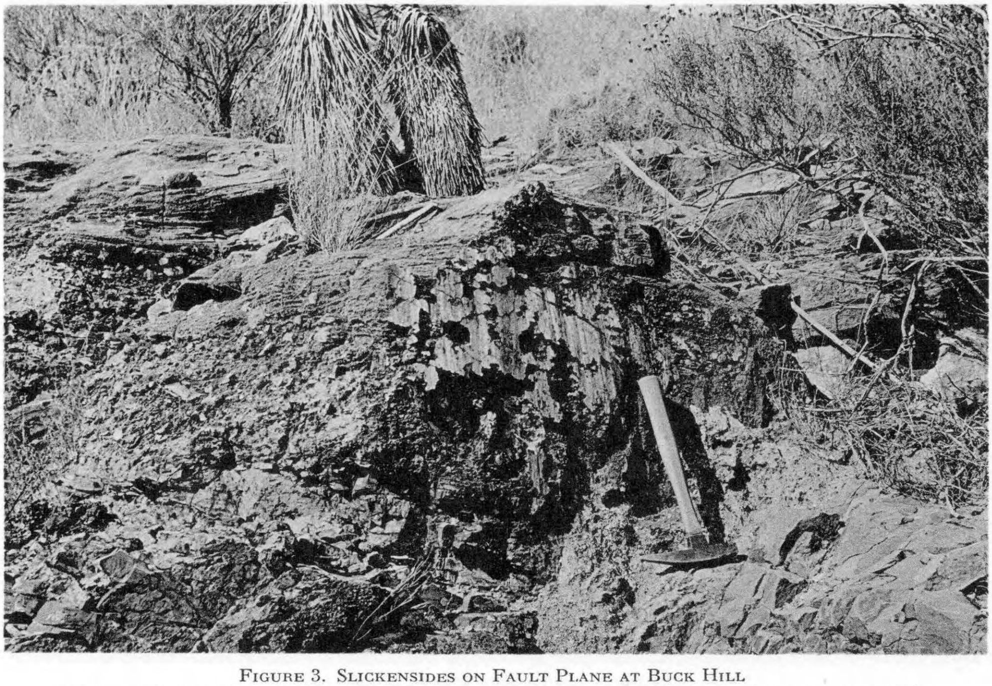


FIGURE 3. SLICKENSIDES ON FAULT PLANE AT BUCK HILL
Syenite on right is downthrown against basal conglomerate member of the Pruett formation on left.

RELATIONSHIPS OF IGNEOUS ROCKS

A variety of volcanic and sedimentary rocks is represented in the conglomerate beds which contain abundant dense and vesicular basaltic types and dense to porphyritic light-colored aphanites such as rhyolite and trachyte. Locally pebbles of fine-grained syenite are common. The sedimentary pebbles are largely chert and fine-grained limestone. Coarse sand commonly is associated with the upper conglomerate. Sand and tuffaceous material cement the conglomerates.

Stratigraphic relations.—In the Buck Hill quadrangle and in the northern part of the Jordan Gap quadrangle the Duff tuff is easily delimited by the Cottonwood Spring basalt at the base and by the Mitchell Mesa rhyolite at the top. In view of the thinning of the Cottonwood Spring flows, the Duff tuff in places may have been deposited directly on the Pruett tuff. Such a condition has not been recognized to date in the areas studied.

Mitchell Mesa Rhyolite

Definition and description.—The thin sheet of rhyolite capping Mitchell Mesa in the northwestern corner of the Buck Hill quadrangle is named for the mesa. The rhyolite resting on the Duff tuff covers about 3 square miles of Mitchell Mesa and is an important lithologic unit in this region as the caprock of the high mesas.

The rhyolite is easily recognized by its pink color and prominent glassy rounded phenocrysts of quartz and opalescent tabular phenocrysts of sanidine. The phenocrysts, rarely exceeding 0.2 inch in length, are set in a dense pink or reddish-gray groundmass. The uniform texture of the rock is broken by light-gray vesiculated areas and by red inclusions of baked and silicified ash. The fracture is subconchoidal to irregular. The weathered rock is dark reddish gray (rusty) or black. Unlike the pitted surface of weathered Crossen trachyte, the weathered surface of the rhyolite commonly shows numerous small protuberances of the more resistant phenocrysts.

The rhyolite on the southern edge of Mitchell Mesa is 38 feet thick and probably does not exceed 50 feet on the mesa. A similar thickness caps Whirlwind Mesa just west in the Jordan Gap quadrangle, but Graham (1942) measured 70 feet of rhyolite on the rim of Antelope Mesa 10 miles southwest of Mitchell Mesa and 150 feet on McKinney Mountain.

Petrography.—The fine-grained groundmass consists of quartz, alkalic feldspar, and unidentified material which may be rhyolitic glass and its devitrification products. Magnetite, zircon, and apatite are accessory minerals. Alteration products include small amounts of limonite, hematite, and leucoxene. The rock owes its pink color to finely disseminated hematite. There is some silica (chalcedony) of late introduction. The phenocrysts are quartz and sanidine, rounded and embayed by magmatic resorption. Optical data for the feldspar are $\alpha = 1.522$, $\beta = 1.528$, $\gamma = 1.528$; all $\pm .002$. (-) 2V is small. The optic plane is normal to 010, and Z = b; $X \wedge a = 5° +$. The dispersion is $r > v$.

Chemical analysis.—A chemical analysis of the Mitchell Mesa rhyolite and analyses of other rhyolitic rocks from Trans-Pecos Texas are given in Table 8. The high percentage of potash (6.34 per cent K_2O) in the analyzed sample of Mitchell Mesa rhyolite is noteworthy, because the analyses of rhyolitic rocks from Trans-Pecos Texas indicate these rocks are sodi-potassic. The closest approach to the composition of the Mitchell Mesa rhyolite is an analysis of a potassic rhyolite from the Solitario (Table 8, No. 2). This analysis, however, appears to be of a weathered specimen, and because soda undergoes greater losses than potash by weathering the analysis may deviate considerably from the composition of the fresh rock. The analyses of rocks from near Shafter (Fig. 2) and from west of Paisano Mountain (Table 8, Nos. 3, 4) are typical of available analyses of rhyolitic rocks in this part of Texas.

Stratigraphic relations.—The Mitchell Mesa rhyolite is the youngest rock of the volcanic series in the Buck Hill quadrangle. In Goat Mountain, 6 miles north in the Alpine quadrangle, and in the Jordan Gap quadrangle younger unnamed tuff beds and flows occur above the rhyolite. Reconnaissance work in these areas indicates the Mitchell Mesa rhyolite is a flow.

TABLE 8.—*Chemical analyses of Mitchell Mesa rhyolite and other rhyolites from Trans-Pecos Texas*

	1	2	3	4
SiO_2	78.83	76.23	75.12	72.86
Al_2O_3	9.95	12.11	10.94	11.74
Fe_2O_3	1.40	.42	2.88	2.71
FeO	.10		.86	1.66
MgO	.16	.46	.07	.06
CaO	.35	.36	.20	.24
Na_2O	1.78	1.40	4.46	4.63
K_2O	6.34	4.93	4.54	4.92
H_2O +	.41	1.47	.19	.40
H_2O −	.11	1.80	.18	.51
CO_2	.27	—	.04	tr.
TiO_2	.20	.13	.20	.20
P_2O_5	.03	.01	none	tr.
MnO	.08	—	.08	.07
BaO	tr.	—	none	none
SrO	n.d.	—	none	none
Li_2O	n.d.	—	tr.	tr.
Rare earths	n.d.	—	.04	.05
SO_3	n.d.	—	none	—
S	tr.	—	.05	tr.
ZrO_2	n.d.	—	.13	.28
Ignition loss	—	.92	—	—
	100.01	100.24	99.98	100.33
Sp. gr.	2.596	—	2.617	2.635

1. Rhyolite porphyry capping Mitchell Mesa. Cat. No. 599. Sp. gr., 23.4°/4°. S. S. Goldich, analyst.
2. Potassic rhyolite, East Tank, Solitario. Phenocrysts of quartz and orthoclase. Groundmass of alkali feldspar and quartz. R. B. Ellestad, analyst (Lonsdale, 1940, p. 1620).
3. Rhyolite near Shafter, Shafter quadrangle. "*Liparose near alaskose.* Phenocrysts of sanidine and quartz. Groundmass of alkali-feldspar, quartz, riebeckite (?), and aegirite. Spherulitic bands traverse the rock. Sp. gr., 2.617, 15.5°." W. F. Hillebrand, analyst (Clarke, 1904, p. 74).
4. Rhyolite west of Paisano Mountain, Alpine quadrangle. "*Liparose.* Contains alkali-feldspars, quartz, arfvedsonite, and aegirite. Sp. gr., 2.635, 15.5°." W. F. Hillebrand, analyst (Clarke, 1904, p. 74).

Volcanic Section in Elephant Mountain

Principal features.—On the southern slope of Elephant Mountain a considerable thickness of the Pruett tuff is overlain by flows of the Sheep Canyon basalt. The flows pinch out to the north, and the massive syenite which caps Elephant Mountain in the Alpine quadrangle lies on both the basalt and the tuff (Pl. 6). In the Buck Hill quadrangle the southern end of the mountain is downthrown along northwest-trending faults. On the northeast side of the larger fault the Cretaceous formations are exposed, and the Boquillas is overlain by the Pruett. Southwest of the fault the Cretaceous does not crop out, and the lower Pruett beds are covered by alluvium.

Pruett formation.—The Pruett formation in the Elephant Mountain area is 500–600 feet thick, of which approximately 300 feet is described in the section (Appendix, Section No. 9) measured in the large gully on the southern slope of the mountain. The basal beds are tuffaceous conglomerate and sandstone or light-yellow to gray sandy tuff which weathers to a characteristic bright yellow. These beds are succeeded by varicolored, but dominantly gray, tuff. In the lower part of the section the tuff is massive with indistinct stratification. It is well lithified and weathers to pebbly nodular gravel. There are a few minor lenses of breccia and conglomerate. In the upper part sorting and stratification are better developed, and thin layers of calcareous tuff and fresh-water limestone interfinger with the tuff.

Sheep Canyon basalt.—There are at least three thick flows of the Sheep Canyon basalt in the southern slope of Elephant Mountain. Along the line of section (Appendix, Section No. 9) the lowest flow is 88 feet thick with an amygdaloidal top 25–30 feet thick. The lower part of the flow is dense porphyritic basalt. Light-gray to brown cherty limestone, 4–13 feet thick and containing silicified fresh-water gastropods, lies between the first flow and a middle porphyritic basalt flow 121 feet thick. Plagioclase phenocrysts, as much as 1 inch long, are contained in a dark fine-grained groundmass. The upper 20–30 feet of the flow is vesicular with numerous chalcedony, jasper, and calcite fillings. A bed of calcareous tuff with lenses of limestone generally separates the middle from the upper flow, but is missing along the line of section. This calcareous bed usually is 5 feet and locally as much as 15 feet thick. The upper basalt flow is 171 feet thick, but an interval of 50 feet above the highest exposure is covered, and the amygdaloidal zone expected at the top of the flow was not found, so the thickness of 380 feet measured for the flows probably does not represent the total thickness. A probable maximum thickness is 450 feet. The Sheep Canyon basalt flows thin rapidly northward, and on the east side of Elephant Mountain, 1¼ miles north of the Buck Hill quadrangle, the flows are absent (Pl. 6). A similar pinch-out occurs on the west side of the mountain 2½ miles north of the Buck Hill quadrangle.

An analysis of the porphyritic basalt from Elephant Mountain (Table 5, No. 3) closely resembles the porphyritic Sheep Canyon basalt on Crossen Mesa. The Elephant Mountain sample was collected in a large gully near the base of the basalt, 105 feet thick, overlain by 10 feet of light-gray fresh-water limestone beneath the syenite. Heavy talus obscures much of the outcrop, and the field observations are inconclusive as to which of the three Elephant Mountain flows is represented. The sample was selected for analysis because it represents the freshest material collected. Approximately 1000 feet north of this locality the basalt feathers out, and the syenite rests on limestone and tuff of the Pruett formation.

Stratigraphic relations.—The tuff, conglomerate, sandstone, and fresh-water limestone beds in Elephant Mountain are part of the Pruett formation. Large low-spired gastropods collected from the lower part of the section are similar to those collected from the ash at the base of Crossen Mesa west of Calamity Creek. Fresh-water limestone beds in the tuff and between the basalt flows in the Elephant Mountain area closely resemble the limestone in the Sheep Canyon area west of Calamity Creek (Pl. 6). In both areas *Goniobasis* is common in the limestone. North of Elephant Mountain the tuff beds are overlain by the Crossen trachyte. C. L. Baker (personal communication, 1941) found tuff, calcareous tuff, and fresh-water limestone, 500 feet thick capped with a trachyte flow 120 feet thick, resting on the Cretaceous limestone on the western flank of Mt. Ord 12 miles north of Elephant Mountain.

In summary the following points support the correlation of the volcanic rocks in Elephant Mountain with the Pruett-Sheep Canyon basalt sequence west of Calamity Creek: (1) The stratigraphic succession of tuff, calcareous tuff, fresh-water limestone, and basalt flows in two areas is similar. (2) Fossils in the fresh-water limestone in the tuff and between the basalt flows are similar. (3) The basalt flows in the two areas are similar chemically and are porphyritic; they are the only porphyritic basalts known in the region. (4) The flows in both areas occupy former stream channels which are part of the ancient drainage system developed after extrusion of the Crossen trachyte and before extravasation of the Sheep Canyon basalt.

QUATERNARY ALLUVIUM

Alluvial deposits cover large areas in the Buck Hill quadrangle and range from clay and silt to boulders. The deposits are chiefly basin fill which accumulated in Green Valley to a thickness of 30 feet or more. Calamity Creek, The Ditch, and Terlingua Creek in many places are steep-walled arroyos which have cut through the alluvium into the bedrock.

Albritton and Bryan (1939) on the basis of disconformities have divided the alluvial deposits in the valley flats of the southern Davis Mountains into three formations, from oldest to youngest: (1) Neville, (2) Calamity, and (3) Kokernot. In the present investigation the alluvium is not differentiated.

INTRUSIVE IGNEOUS ROCKS

General Statement

Syenitic igneous rocks with definite intrusive relationships form two prominent hills in the southern part of the quadrangle. In the south-central part syenite forms the flat-topped Buck Hill for which the quadrangle is named. West of Buck Hill a syenite plug is the core of Straddlebug Mountain.

Approximately 4 miles north of Buck Hill a small mass of dense black basalt forms Butcherknife Hill.

Microsyenite

Syenite of Buck Hill.—The syenite of Buck Hill is a light-gray, fine-grained, even-textured rock weathering to yellowish brown. The tabular mass is cut by two normal faults that divide it into three segments with the middle block downthrown. The largest and southwestern segment measures 4500 feet in length in a northwest-southeast direction and 3000 feet across at its widest part. The middle segment is 2500 feet wide at its southeastern end, but splits to the northwest into a number of narrow offshoots. The northeastern segment is about 2000 feet long and 700 feet wide. The greatest overall dimension of the syenite mass is 6500 feet along an east-west line.

The syenite is a small intrusive which apparently spread sill-like at or near the contact of the thin-bedded Boquillas limestone and the overlying basal beds of the Pruett. The mass averages 65 feet thick, but it may have been thicker as its roof has been removed. In the northeastern segment thin-bedded Boquillas limestone is sandwiched between massive sheets of the syenite (Pl. 5, fig. 2). On the southeastern side of the hill the middle segment of the syenite overlies a thin bed of the basal Pruett conglomerate which rests on the Boquillas limestone. The conglomerate was not found on the northwestern side of the middle segment where narrow dikes or offshoots from the main syenite mass cut the Boquillas. One of these apophyses is over 2000 feet long. In the southwestern segment, which is the upthrown side of the larger fault, the syenite lies on a considerable thickness, 14–30 feet, of the Pruett formation. Southeast of Bench Mark 4203 there are xenoliths of the Pruett sandstone in the syenite.

Syenite of Straddlebug.—-The syenite of Straddlebug Mountain closely resembles that of Buck Hill, but it is more weathered. The small plug measures less than 1000 feet across, but, unlike the Buck Hill intrusive, it resulted in a pronounced deformation and doming of the sedimentary rocks. The oldest beds brought to surface are Buda limestone; the youngest are lower beds of the Boquillas. The sedimentary rocks dip away from the hill on all sides except on the north where they are covered by alluvium on the downthrown side of the Chalk Draw fault. Dips as high as 80° were observed on the southwest side of Straddlebug, but usually they are considerably less. At the contact with the syenite the Boquillas flags have been baked to dark, fine-grained marble. On the southwest side of Straddlebug Mountain a sill of syenite not more than 6 feet thick intrudes the Boquillas and appears to have had little effect on the limestone. The sill is estimated to be about 50 feet above the base of the Boquillas formation.

Petrography.—The freshest specimens of syenite from Buck Hill show some weathering, and in samples from Straddlebug Mountain the weathering is pronounced. The feldspars are dusty, and the ferromagnesian minerals are altered to limonite. The texture is fine-grained, trachytic to granular. Extinction in the feldspar laths is anomalous, and the twinning is indistinct. Large anhedral grains of feldspar appear to be a microperthitic intergrowth. Nepheline was not identified, and zeolitic material is rare. In the syenite of Buck Hill there is some hornblende with deep olive-green to brown pleochroism and a small amount of biotite with light-yellow to reddish-brown pleochroism. Magnetite and apatite are accessory. The intrusives are alkalic microsyenite.

Chemical analysis.—A chemical analysis of a sample of syenite from Buck Hill is given in Table 9 in which three analyses of similar syenites are included. Ferric and ferrous oxides and some of the minor constituents were determined on a sample of the Straddlebug syenite. The relatively large proportion of ferric iron is indicative of the weathering of these masses. The percentage of alkalies is large, and calculated normative nepheline is 2 per cent of the Buck Hill rock (Table 10).

Age and correlation.—Because of similarity in composition and because both the Straddlebug Mountain and Buck Hill intrusives are on an east-west line of structural weakness, the two intrusives may be related and of the same age. The syenite of Buck Hill is clearly younger than the basal conglomerate of the Pruett formation.

Many syenitic intrusives in this region closely resemble the microsyenite of Buck Hill and Straddlebug Mountain. Two conspicuous masses are the syenite on Elephant Mountain and the Santiago Peak intrusive east of the quadrangle. The Elephant Mountain syenite

TABLE 9.—*Chemical analyses of syenite from Buck Hill and other localities in Trans-Pecos Texas*

	1	2	3	4	5
SiO_2	60.98	—	62.46	59.36	59.62
Al_2O_3	17.35	—	17.10	18.20	17.89
Fe_2O_3	5.46	5.25	2.49	6.19	3.97
FeO	.49	.08	2.65		1.83
MgO	.33	—	.28	.15	.75
CaO	1.38	—	1.27	1.64	2.78
Na_2O	5.98	—	6.84	5.99	6.20
K_2O	5.58	—	5.44	5.28	4.55
H_2O +	.81	—	.49	.22	.71
H_2O −	.26	—	.15	1.10	.38
TiO_2	.50	—	.38	tr.	.66
ZrO_2	.16	—	.10	—	—
CO_2	.32	—	tr.?	—	—
P_2O_5	.28	.10	.11	tr.	.26
MnO	.21	.18	.18	tr.	—
BaO	.03	tr.	none	—	—
SrO	n.d.	—	none	—	—
Li_2O	n.d.	—	tr.	—	—
S	.00	.00	none	—	—
Cl	n.d.	—	n.d.	.31	—
Rare earths	n.d.	—	.03	—	—
	100.12		99.97	98.44	99.60

1. Alkalic microsyenite of Buck Hill. Sp. gr., 25°/4°, 2.659. S. S. Goldich, analyst.
2. Alkalic microsyenite of Straddlebug Mountain. S. S. Goldich, analyst.
3. Pulaskite, Santiago Mountain, Santiago Peak quadrangle. Sp. gr., 2.581, 25.5°. W. F. Hillebrand, analyst (Clarke, 1904, p. 75).
4. Alkalic syenite, Elephant Mountain, Alpine quadrangle. L. A. Mikeska and W. A. Felsing, analysts (Schoch, 1918, p. 185).
5. Analcitic microsyenite, Sawmill Mountain, Terlingua-Solitario region. R. B. Ellestad, analyst (Lonsdale, 1940, p. 1620).

rests on tuff and fresh-water limestone of the Pruett formation and on flows of the Sheep Canyon basalt. The Elephant Mountain syenite (Hardin, 1942) ranges from 800 to 1100 feet in thickness, but some of the upper part may have been removed by erosion. In the valley just north of Elephant Mountain on the Neville ranch three small intrusives of similar syenite pierce both the Boquillas limestone and the basal Pruett tuff (Pl. 6). These probably are the feeders for the Elephant Mountain syenite which is considered to be intrusive. The time of intrusion is post-Sheep Canyon basalt and probably post-Duff.

In the Santiago Peak quadrangle Eifler (1943, p. 1635) found Cenozoic sandstones and conglomerates on the eroded Boquillas surface which on the southern and western sides of Black Mountain are overlain by syenite capping the mountain. At Santiago Peak the sandstone is overlain by white and lavender tuffs 800–900 feet thick. The syenite of Santiago Peak towers 1200 to 1300 feet above the highest level at which the tuff was found. These figures are significant because they indicate the Santiago Peak syenite probably was intruded into a sequence with a minimum thickness of the Buck Hill volcanic series. The sandstone and conglomerate may be the equivalent of the basal conglomerate member of the Pruett formation, and the total thickness of sandstones and tuff corresponds closely to the thickness of the Pruett. Originally deposits equivalent to the combined thickness of the Pruett and the Duff probably covered the region, and into these deposits the syenitic magma of Santiago Peak was intruded.

The syenite rocks of Santiago Peak and of Elephant Mountain are mineralogically similar and on a line connecting these masses are other large syenitic intrusives in the Santiago Peak quadrangle. These intrusives, the syenite of Buck Hill and of Straddlebug Mountain, and a large number of others in this region probably are closely related genetically.

Butcherknife Basalt

General features.—The Butcherknife basalt is a fresh, black, very fine-grained rock with a conchoidal fracture. Because the rock spalls readily, the upper slopes of the hill are covered with basalt fragments, so the relations of the basalt to the sediments could not be determined. Near the base of the hill tuffaceous coarse sandstone, sandy and calcareous tuff, and gray ash with thin beds and nodules of limestone of the basal Pruett rest on Boquillas limestone. The Boquillas strata away from Butcherknife Hill are essentially flat-lying, but the Pruett beds closer to the basalt show local disturbance, and on the northwest side of the hill dip up to 25° NW. The high dips in the Pruett beds in the vicinity of Butcherknife

TABLE 10.—*Chemical analyses and norms of Buck Hill rocks*

(S. S. Goldich, analyst)

	Sheep Canyon basalt			Cottonwood Spring basalt		Butcher-knife basalt	Syenite of Buck Hill	Potato Hill andesite	Crossen trachyte	Mitchell Mesa rhyolite	Volcanic tuff	
	Hill 4321	Potato Hill	Elephant Mountain	Potato Hill	Cottonwood Spring						Pruett	Duff
ANALYSES												
SiO_2	44.33	45.65	45.97	46.90	48.08	48.53	60.98	61.46	71.17	78.83	69.73	70.57
Al_2O_3	14.69	16.48	17.26	15.82	15.87	17.42	17.35	14.85	12.64	9.95	12.06	12.19
Fe_2O_3	4.27	6.92	2.84	4.18	3.74	3.46	5.46	7.23	4.28	1.40	1.06	1.29
FeO	8.68	6.40	9.18	7.74	7.49	7.48	0.49	0.68	0.11	0.10	0.13	0.09
MgO	4.88	4.05	5.63	4.48	3.86	3.10	0.33	0.74	0.13	0.16	0.88	0.60
CaO	7.00	7.48	7.87	6.24	5.76	6.60	1.38	5.23	1.05	0.35	2.16	1.43
Na_2O	3.46	3.38	4.33	3.80	4.50	5.13	5.98	3.75	3.91	1.78	0.78	1.80
K_2O	2.15	1.42	1.00	2.32	2.43	2.38	5.58	2.58	5.05	6.34	4.17	5.09
H_2O+	2.15	2.10	1.57	1.93	2.17	1.68	0.81	0.22	0.23	0.41	5.05	3.36
H_2O-	1.09	1.39	0.20	1.13	0.97	0.26	0.26	0.17	0.12	0.11	3.31	2.84
CO_2	0.07	0.37	0.00	0.02	0.02	0.02	0.32	0.10	0.19	0.27	0.01	0.14
TiO_2	3.64	3.21	2.87	2.79	2.68	2.53	0.50	1.52	0.56	0.20	0.18	0.22
P_2O_5	2.99	0.87	0.96	1.97	1.81	1.10	0.28	1.13	0.07	0.03	0.04	0.08
MnO	0.23	0.18	0.17	0.21	0.23	0.21	0.21	0.11	0.14	0.08	0.01	0.01
BaO	0.17	0.09	0.07	0.23	0.12	0.06	0.03	0.18	0.08	tr.	0.13	0.04
SrO	0.14	0.09	0.10	0.10	0.09	0.13	n.d.	n.d.	n.d.	n.d.	0.09	n.d.
S	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	tr.	tr.	0.00	0.00
ZrO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.16	n.d.	n.d.	n.d.	n.d.	n.d.
Total	99.94	100.08	100.02	99.86	99.82	100.10	100.12	99.95	99.73	100.01	99.79	99.75
Sp. gr. (t°/4°)	2.818	2.829	2.874	2.823	2.762	2.808	2.659	2.764	2.648	2.596	2.368	2.421

NORMS

Q	—	1.92	—	—	—	—	—	20.94	27.66	44.04		
or	12.79	8.34	6.12	13.34	14.46	14.46	33.36	15.57	30.02	37.25		
ab	29.34	28.82	29.87	31.96	38.25	33.27	54.49	31.96	33.01	15.20		
an	15.29	25.58	25.02	18.35	15.85	17.51	—	15.85	1.95	—		
ne	—	—	3.41	—	—	5.25	1.99	—	—	—		
C	1.02	—	—	0.41	—	—	—	—	—	0.20		
di	—	3.27	6.80	—	1.36	6.64	1.73	—	0.22	—		
wo	—	—	—	—	—	—	0.35	—	—	—		
hy	14.91	9.76	—	12.82	2.29	—	—	1.85	0.20	0.40		
ol	4.15	—	15.23	4.85	9.74	8.55	—	—	—	—		
mt	6.26	9.98	4.18	6.03	5.34	5.10	0.93	—	—	—		
hm	—	—	—	—	—	—	4.80	7.20	4.32	1.44		
il	6.84	6.08	5.47	5.32	5.17	4.71	0.91	1.67	0.46	0.30		
tn	—	—	—	—	—	—	—	1.57	0.98	—		
ru	—	—	—	—	—	—	—	—	—	0.08		
ap	7.06	2.02	2.35	4.70	4.37	2.69	0.67	2.69	0.17	0.07		
cc	0.20	0.90	—	tr.	tr.	tr.	0.70	0.20	0.50	0.60		
Z	—	—	—	—	—	—	0.18	—	—	—		

Hill and the freshness, the even dense texture, the irregular jointing, and the absence of flow breccia, flow structure, or vesiculation in the basalt suggest that the rock is not a flow but rather a small intrusive.

Petrography.—The Butcherknife basalt is holocrystalline but very fine-grained. The texture is intergranular ophitic with small grains of pyroxene, euhedral crystals of magnetite, alkalic feldspar, and minor analcime interstitial to the lathlike plagioclase crystals. The largest plagioclase crystals measure 0.3 mm. in length, but the average is much less. Magnetite makes up 10–15 per cent of the rock. Apatite also is abundant in small prismatic crystals. The rock is classified as analcime trachybasalt.

Chemical analysis.—The chemical analysis of the Butcherknife basalt (Table 7, No. 3) is characterized by its relatively large content of alkalies. The analysis somewhat resembles that of samples of the Cottonwood Spring basalt and those of the Sheep Canyon basalt (Table 5) and of basaltic rocks from the Terlingua-Solitario region. The Butcherknife basalt closely approaches the composition of an analcime syenogabbro from Cigar Mountain.

Age and correlation.—The Butcherknife basalt is younger than the lowermost Pruett. Although the Butcherknife basalt cannot be correlated definitely with either the Sheep Canyon basalt or the younger Cottonwood Spring basalt, it is much like them in composition.

IGNEOUS PETROLOGY

The chemical analyses of the igneous rocks from the Buck Hill area and the calculated norms (Table 10) bring out the alkalic affinities which characterize the Tertiary igneous rocks of Trans-Pecos Texas, The silica content of the analyzed samples ranges from 44.3 to 78.8 per cent, and total alkalies (Na_2O and K_2O) from 4.8 to 7.5 per cent. Relatively large amounts of TiO_2 and P_2O_5 mark the low-silica lavas. Notable quantities of SrO and BaO were determined in these samples; strontia ranges from 0.09 to 0.14 per cent, and baria, from 0.06 to 0.23 per cent. The Buck Hill rocks are similar in composition to the igneous rocks of the Terlingua-Solitario region described by Lonsdale (1940), although certain rock types from the southern region are not represented in the analyzed specimens from the Buck Hill area, from which new types also are recorded. Most notable of the latter is the Mitchell Mesa rhyolite, a potassic rock in contrast with the sodi-potassic high-silica rocks of the Terlingua-Solitario region. A rough comparison of normative minerals of the two groups follows:

	No. of Analyses	*or*	*ab*	*an*	*ne*	*ol*
Buck Hill	10	6–37	29–55	0–26	0–5	0–15
Terlingua-Solitario	21	8–31	5–55	0–20	0–11	0–16

The analyses from these areas together with three older analyses plotted in the usual silica-oxides variation diagram give relatively smooth curves for the group of 34 samples (Fig. 5). Certain features of the variations are worthy of comment,

(1) Strong curvature of the variation lines suggests strong fractionation of the liquids from which the rocks were derived.

(2) The downward curvature for K_2O in the high-silica range is notable. Points for the curve require little smoothing except for samples of the Potato Hill andesite and the Mitchell Mesa rhyolite. The andesite analysis is anomalous in its abnormally high silica content which is the result of the introduced quartz and chalcedony of the amygdules. By subtracting silica equivalent to the normative quartz and recalculating, the andesite can be plotted at 51.4 per cent SiO_2. The recalculated K_2O then is 3.3 per cent, and this value fits the K_2O curve well. Similarly points for other constituents are shifted to the left largely eliminating the apparent anomalous positions of andesite points plotted on Figure S. Extrapolation from the main K_2O line to the Mitchell Mesa rhyolite gives a line trending upward in the high-silica range which is in sharp contrast with the plotted curve for the Trans-Pecos rocks but more nearly like the usual variations of K_2O in rock series.

(3) As a group, the analyzed lavas from the Buck Hill area contain relatively more total iron oxide (Fe_2O_3) than the Terlingua-Solitario rocks.

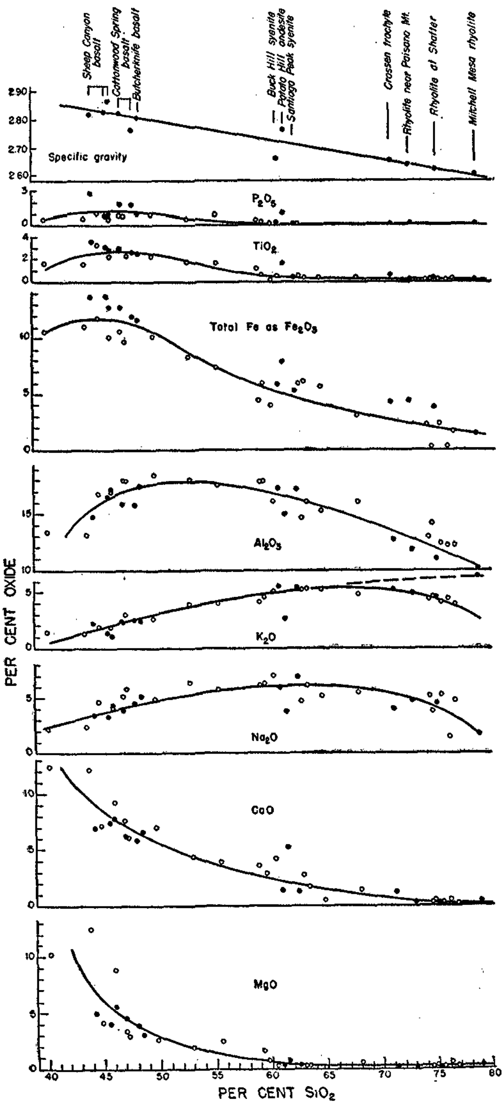


FIGURE 5.—VARIATION DIAGRAM OF BUCK HILL AND SIMILAR IGNEOUS ROCKS

Circles represent analyzed samples from the Terlingua-Solitario region; analyses of rhyolite rocks from Shafter and Paisano Mountain and of syenite from Santiago Peak are included

Broader regional studies of the Cenozoic igneous rocks of Trans-Pecos Texas are now in progress, and a larger number of analyses may show greater diversity and relations other than those suggested by the present analyses. Lonsdale (1940) has discussed the chemical characteristics and origin of the Terlingua-Solitario region comparing them to alkalic subprovinces at the front of the Rocky Mountains.

STRUCTURAL GEOLOGY

General Features

The effects of two crustal disturbances can be seen in the Buck Hill region. The Laramide revolution at the close of the Cretaceous resuited in board upwarping and erosion prior to the deposition of the Tertiary Pruett formation. In the Buck Hill and Elephant Mountain areas there is a discordance between the dips in the Cretaceous which normally do not exceed 4° and in the overlying basal Pruett conglomerate and sandstone. Along the 02 ranch road south of Crossen Mesa dips in the Pruett are as high as 14°, but the beds flatten rapidly northward. Dips in the underlying Boquillas limestone are 2°–3° N. South of the road at this locality the basal conglomerate occupies a swale or depression on the old Boquillas surface. At Hill 3927 northeast of Butcherknife Hill the basal Pruett beds dip 8° N. The high dips in these beds are intrepreted as initial dips off hills on the Boquillas erosion surface.

Faults of late Tertiary or early Quaternary age are the outstanding structural features, but the Buck Hill volcanic series has been deformed into broad open folds. The faults are all of the normal type and cut the youngest rock of the volcanic series and also the syenite intrusives. In the Buck Hill quadrangle there are two major faults or fault zones along which a central block is depressed structurally. The eastern part of the quadrangle is structurally high. Cretaceous rocks are not exposed west of Whirlwind Spring in the northern part of the area and west of The Ditch in the southern part, except at Straddlebug where the Cretaceous strata are domed around the syenite plug. From Whirlwind Spring northwest in the quadrangle and west in the Jordan Gap quadrangle progressively younger rocks of the Buck Hill volcanic series are exposed.

Effects of older orogenies that produced the structure in the Paleozoic rocks in the Marathon Basin (King, 1937) to the northeast and in the Solitario (Sellards,. 1932, p. 55–131;

Baker, 1934, p. 177–180) to the south cannot be seen as rocks older than the Georgetown limestone do not crop out in the Buck Hill quadrangle. Likewise, little information concerning the Laramide deformation is available from work in the Buck Hill area; therefore, only the Cenozoic structural features are here considered.

Cenozoic Folding

The Buck Hill volcanic series in the Buck Hill and Jordan Gap quadrangles has been folded into a broad northwest-plunging nose. In the northern part of the Buck Hill quadrangle the regional dip is less than 2° N. or NW. The scarps of the Pruett tuff beneath the Cottonwood Spring basalt and of the Duff tuff beneath the Mitchell Mesa rhyolite face southward toward Green Valley. In the western part of the quadrangle remnants of the Cottonwood Spring flows cap hills north and south of the O2 ranch house, and west of these hills in the Jordan Gap quadrangle the scarps of the basalt-capped cuestas face southeastward toward Green Valley with a gradual shift from an east-west strike in the Buck Hill quadrangle to a north-south strike in the Jordan Gap quadrangle. Similarly, the outcrop of the Mitchell Mesa rhyolite swings southward in the high mesas of the Jordan Gap quadrangle and describes a rough arc with a change from a northerly dip to a westerly and southwesterly dip in western and southwestern Jordan Gap quadrangle. These structural features indicate a broad fold whose axis plunges northwest in a direction roughly parallel to the northwest-trending faults of the western part of the Buck Hill quadrangle.

Cenozoic Faulting

Walnut Draw and related faults.—The Walnut Draw fault zone, named for Walnut Draw on the western edge of Crossen Mesa, consists of roughly parallel and imbricate faults trending southeast that set Crossen Mesa off from the structurally depressed block to the southwest. The fault zone can be traced continuously to the vicinity of Whirlwind Spring, but south of Dark Canyon and east of Whirlwind Spring the master fault is covered by alluvium. From Whirlwind Spring the fault continues to the east boundary of the quadrangle and is marked by the southward-facing Boquillas cuesta. The Walnut Draw fault zone within the quadrange is 15 miles long but continues eastward in the Santiago Peak quadrangle and northward in the Alpine quadrangle.

The displacement along the Walnut Draw fault ranges from 300 feet at the eastern end, where the upper beds of the Boquillas formation are dropped down against the lower part of the Boquillas and against the Buda limestone, to approximately 1000 feet at the northwestern end where the Duff tuff is downthrown against the Cottonwood Spring basalt. Between these points the displacement on any one fault of the zone is small, but the cumulative result is a stratigraphic throw of approximately 1100 feet (Fig. 6).

Walnut Draw is a graben formed by two faults of the zone that are as much as half a mile apart. The downthrown block is tilted and dips 9° NW., so the throw of the faults increases in that direction. Flows above the Crossen trachyte on the mesa occur 400–500 feet lower in the graben, and additional displacement up to several hundred feet is effected by a third fault that makes a horst of the southwestern block of the Walnut Draw graben and brings the Duff tuff down against the Cottonwood Spring basalt. The latter fault is the master of the zone. Vesicular basalt on the southwest side of this fault south of the trachyte-capped spur is mapped as Cottonwood Spring basalt but may be Sheep Canyon basalt, indicating a minimum displacement of 500 feet with a probable maximum of 850 feet. In the fault zone west of the Pruett ranch house the displacement is taken up in a number of faults, and slivers of the Crossen trachyte have a pronounced roll or dip to the southwest indicating that displacement in part was accomplished by bending of the volcanics.

East of Whirlwind Spring the Boquillas limestone forms a southward-facing cuesta in the upthrown scarp along the eastward continuation of the Walnut Draw fault zone. Most of the Pruett formation has been displaced along the concealed fault between Whirlwind Spring and the Boquillas outcrop to the east. This fault, covered by alluvium between the 02 ranch road and Dark Canyon, is the master fault. It probably parallels the mapped fault on the west side of the Whirlwind Spring spur, but the mapped fault is a minor one, and east of Hill 4631 the Cottonwood Spring basalt is downthrown against the upper breccia-conglomerate member of the Pruett with a displacement of 60 feet.

Faults of the central area.—South of Mitchell Mesa numerous northwest-southeast faults cut the Cottonwood Spring basalt. The displacement on these faults usually is less than 100 feet, but their net effect is an appreciable lowering of the volcanics to the southwest. The faults cannot be traced to the southeast because of the alluvium in Green Valley, but in the eastern and central parts of the quadrangle three faults with a northwest trend are mapped, and these also result in a structural lowering to the southwest. The large fault southwest of Butcherknife Hill swings eastward and parallels the Chalk Draw fault, forming a graben. Chalk Draw road follows this alluvium-covered structural depression.

Chalk Draw and related faults.—The east-west Chalk Draw fault structurally dominates the southern part of the quadrangle and has a profound influence on the physiography. Although the fault is traced with difficulty in the incompetent beds of the Pruett tuff and in part is covered by alluvium, it extends practically the breadth of the quadrangle and continues eastward in the Santiago Peak quadrangle to Chalk Draw where it swings to the southeast. The fault was named by C. L. Baker (1934, p. 209), and its upthrown scarp forms the west wall of Chalk Draw valley from the southern part of the Santiago Peak quadrangle to the Rosillos Mountains (Fig. 2).

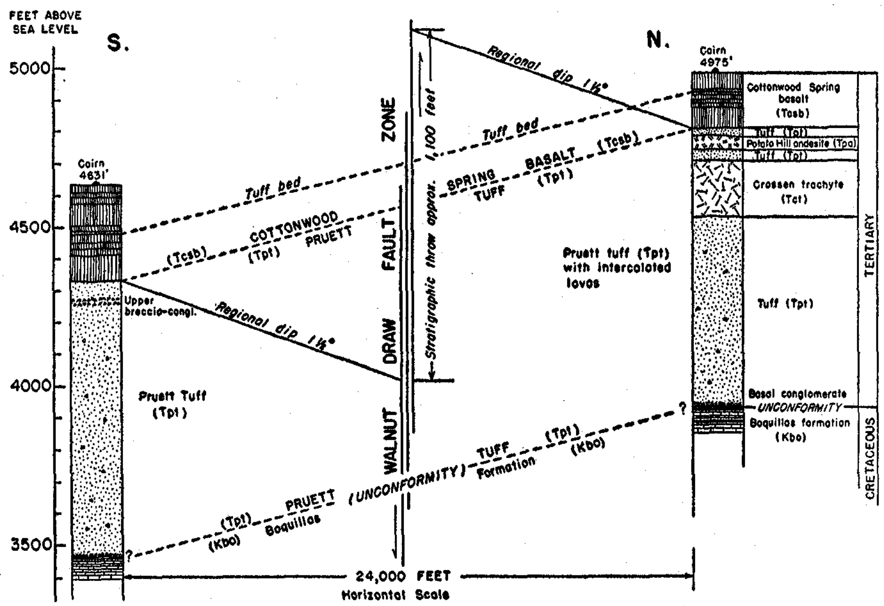


FIGURE 6.—COLUMNAR SECTIONS AT HILLS 4631 FEET AND 4975 FEET
Showing correlation of the Cottonwood Spring basalt flows and interpretation of structure.

Although the southern upthrown block of the Chalk Draw fault in the Buck Hill quadrangle is structurally high, there is a structural lowering from east to west accomplished mainly by a set of northwest-southeast faults. These secondary faults divide the uplifted block into three segments. The easternmost segment is east of the Alpine-Terlingua highway and is capped by the lower flaggy beds of the Boquillas formation which also form the downthrown block on the north side of the Chalk Draw fault. Northeast of Stone Tank the downthrown block dips at an angle of about 7° toward the fault plane and abuts against the Georgetown limestone. The throw on the Chalk Draw fault here is approximately 225 feet, but westward the stratigraphic throw decreases, and the Boquillas beds rest against the Grayson and Buda formations.

The middle segment is largely west of the highway and is capped by the upper limestone beds of the Boquillas. Small grabens result from the northwest-southeast faults in this segment; in one a block of the syenite at Buck Hill is downfaulted, and in a second the basal beds of the Pruett tuff lie in a valley flanked by the Boquillas limestone. The downthrown side of the Chalk Draw fault in this segment is the Pruett tuff, and along the fault the tuff beds are characterized by dips up to 40° NW. The high dips suggest that the throw along Chalk Draw fault may be great, although displacement on the fault cannot be determined.

The third segment in the southwest corner of the quadrangle is composed of the Pruett tuff which is downfaulted against the Boquillas limestone south of Loy Place and also is exposed in The Ditch and in Terlingua Creek. In this area the Chalk Draw fault cuts the north slope of Straddlebug Mountain and is exposed to the west in Terlingua Creek where the tuff beds on the downthrown side of the fault dip 36° NW. The high dips in the Cretaceous strata flanking the syenite plug of Straddlebug Mountain are the result of the intrusive action.

The structural lowering from east to west along the Chalk Draw fault is in keeping with the increasing magnitude of structural depression from east to west along the Walnut Draw fault and a similar lowering from northeast to southwest on the faults in the central part of the quadrangle. The northwest dip of the Pruett tuff beds along the Chalk Draw fault may be related to this increasing displacement.

Elephant Mountain faults.—Two parallel faults trending northwest lower the Sheep Canyon basalt and **Pruett** tuff in the southern tip of the mountain, The displacement on the larger northeastern fault is at least 550 feet. In this corner of the quadrangle the Cretaceous formations attain their greatest altitude, and the top of the Cretaceous is 4550 feet above sea level as compared to 4000 feet above sea level at Buck Hill.

PHYSIOGRAPHY

The Buck Hill quadrangle lies in the Mexican Highlands Province (King, 1937, p. 2) and affords a marked contrast between its northern part containing residual mesas of the southern Davis Mountain front and its southern part occupied largely by the northeastern end of an extensive lowlands, Green Valley. East of the quadrangle is the folded Santiago Mountain range which is continued to the southeast in the Sierra del Carmen (Fig. 2). North and south of the quadrangle the Alpine and Terlingua areas are important centers of Tertiary intrusive action, and in both these areas the prominent physiographic features are the peaks which are igneous plugs uncovered by erosion.

The semiarid climate of Trans-Pecos Texas brings out the resistant quality of the limestones and igneous rocks which form the prominent topographic features. The mesas in the northern part of the Buck Hill quadrangle are of unequal height and altitude, because different flows cap them and because faulting has disturbed the normal relations of the volcanic series. The mesa tops are essentially dip slopes on flows. Mitchell Mesa capped by rhyolite porphyry is the highest point in the quadrangle with an altitude of 5351 feet, and between this mesa and Green Valley there is a maximum relief of 1700 feet.

Crossen Mesa capped by trachyte porphyry is several hundred feet lower than Mitchell Mesa. Hills rising above the trachyte caprock are capped by flows of the Cottonwood Spring basalt. Potato Hill is of this type, and is the highest point on Crossen Mesa (B. M. 5071 feet). The lower mesas southwest of Crossen Mesa are also capped by the Cottonwood Spring basalt and share the low regional northwest dip. The highest points near their southern scarps generally are less than 4500 feet above sea level. The breccia-conglomerate, 60 feet below the top of the Pruett, makes a prominent bench in the tuff below the Cottonwood Spring basalt. The breccia-conglomerate caps a number of spurs; a prominent one is Boat Mountain (Pl. 3, fig. 2).

Small consequent streams on the mesas flow northward on the dip slopes, but the master drainage is southward and opposed to the regional dip. The northward-flowing streams on Mitchell Mesa are captured in the Alpine quadrangle by Walnut Draw and Goat Creek and diverted to the Terlingua drainage by way of Duff Creek and The Ditch. South of Duff Springs a trellis drainage pattern controlled by the northwest-southeast faults has been developed, and the tributaries to Duff Creek occupy small grabens. Two miles south of Duff Spring the valley is half a mile wide, but the present stream flows in a narrow channel 30 feet deep cut in the alluvium.

The central and southern parts of the quadrangle consist of rolling hills and cuestas carved in Cretaceous limestone and shale and of valley flats which are alluvium-filled, structurally low areas. The cuestas are fault scarps with the downthrown side commonly covered by alluvium. The most conspicuous scarp is formed by the Georgetown limestone along the Chalk Draw fault. The Boquillas cuesta along the Walnut Draw fault east of Whirlwind Spring has been breached by Calamity Creek. North of the fault scarp on either side of Calamity Creek are low rounded hills which are typical of the Boquillas formation (Pl. 4, fig. 2). Calamity Creek, like Duff Creek, has cut a steep-walled channel in the alluvium of Green Valley. Similar channels characterize much of the courses of The Ditch and Terlingua Creek in the southwestern part of the quadrangle, and these streams are now actively eroding the Pruett tuff bedrock.

The active downcutting with renewal of erosion of bedrock in this region is attributed by Baker (1934, p. 140) to recent rejuvenation. According to Baker the development of the Rio Grande involved a number of local base levels which have left their record in "erosion-cut or 'pediment' surfaces of the bed rocks in numerous places". Remnants of terraces or benches approximately 50 feet above the present valley level can be seen west of the Alpine highway in the northern part of the quadrangle and in a number of places in the southwestern part. These benches are erosion-cut surfaces on well-indurated Pruett tuff beds with a thin veneer of gravel.

SUMMARY GEOLOGIC HISTORY

The Cretaceous record in the Buck Hill quadrangle is limited; it ranges from Georgetown limestone to calcareous shale of Eagle Ford or lower Austin age. South of the quadrangle, Cretaceous formations (Adkins, 1932, p. 451, 505–512) younger than the Boquillas include the Terlingua, Aguja, and Tornillo formations. The Terlingua and the lower part of the Aguja are marine, but the upper Aguja beds contain black carbonaceous and lignitic shales that mark a change from marine to brackish-water and nonmarine deposition. Remnants of the Terlingua and Aguja formations occur south and east of the Buck Hill quadrangle. Calcareous shale at Hill 3927 northeast of Butcherknife Hill contains lower Austin Foraminifera and may be a remnant of the Terlingua (Austin) formation.

Uplift in late Cretaceous time initiating the Laramide revolution resulted in erosion of the Terlingua, Aguja, and the Tornillo if the latter was deposited in the Buck Hill area. The basal Pruett conglomerate, which rests on the Boquillas limestone in the Buck Hill quadrangle, lies on the Terlingua clay in a number of places in the Agua Fria quadrangle and on the Aguja formation on either side of the Alpine-Terlingua highway southeast of Hen Egg Mountain in the northern part of the Terlingua quadrangle, approximately 20 miles to the south. North of the quadrangle in the vicinity of Mount Ord, the volcanics rest with "well-marked unconformity" (King, 1930, p. 98) on rocks of Washita age. These observations indicate the widespread angular unconformity between the Cretaceous strata and the Tertiary volcanics, with the volcanic series resting on progressively younger Cretaceous rocks as one goes south toward the Chisos Mountains. 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 Mountain area.

West of the Buck Hill region in western Presidio County (Fig. 2) the effects of the Laramide revolution are more pronounced, and the Tertiary volcanics rest on Permian strata in the Shafter area and on folded Upper Cretaceous formations in the Rim Rock country of the Sierra Tierra Vieja. In the latter area near Provenir vertebrate fossils date the Vieja volcanic series as lowermost Oligocene. Abundant igneous boulders in the basal Vieja conglomerate indicate Eocene or possibly late Cretaceous igneous activity with erosion of intrusives and possibly flows to supply the boulders. In contrast with the Vieja conglomerate the basal Pruett conglomerate in the Buck Hill region is composed of well-rounded pebbles and cobbles of limestone and chert. Large angular pieces were derived from the formations immediately below the conglomerate, but igneous pebbles are few or wanting. The first appearance of large igneous pebbles and boulders is in the upper breccia-conglomerate in the upper part of the Pruett tuff, and at approximately this level the intercalated flows appear in the sequence.

The Pruett is assigned tentatively to the Eocene on the basis of fossil gastropods in the fresh-water limestone beds that occur below and above the Crossen trachyte and between flows of the Sheep Canyon basalt. Therefore, these flows can be dated tentatively as Eocene. The younger Potato Hill andesite also may be of Eocene age, but there is no definite evidence for dating the time of its extrusion or of that of the overlying Cottonwood Spring basalt flows. The Duff formation is assigned tentatively to the Oligocene. It is not likely that deposition was continuous, and undoubtedly materials were reworked and locally were removed by streams. Rather large breaks in the tuffs could escape detection because of the nature of the materials.

The various flows in the Buck Hill volcanic series were all more or less weathered and eroded. The Crossen trachyte in Sheep Canyon (Pl. 6) was deeply incised, and the younger Sheep Canyon basalt flows which filled the ancient stream channels rest on fresh-water limestone and on trachyte. The Potato Hill andesite also was deeply weathered, and the variable thickness of the Cottonwood Spring basalt, in part due to thinning or feathering out of the flows, probably is also the result of erosion prior to deposition of the Duff tuff.

Stratification of the tuff and the fresh-water limestone beds indicate that much of the Pruett was deposited in water, probably in large lakes. The calcium carbonate, especially in the lower part of the formation, may have been mechanically derived from the exposed Cretaceous formations, but the thick sequence of tuffaceous limestone in Sheep Canyon and in the Elephant Mountain area was precipitated. The algal structures and charophytes suggest that much of the limestone is of organic origin. The Tertiary lakes probably were temporary and shallow, and the lavas do not show structures or alteration commonly found in subaqueous flows. The source of the volcanic ash is problematical. The finer material could have come from great distances, but the coarser detritus, such as the breccia-conglomerate in the upper Pruett and the conglomerates of the Duff, probably were derived from near-by sources.

In late Tertiary time syenitic and basaltic magmas intruded the Cretaceous and Tertiary formations. The syenite at Buck Hill intruded the lower Pruett beds, and the Elephant Mountain syenite invaded upper beds, coming to rest on the Sheep Canyon basalt. The syenite of Santiago Peak stands 1200 feet above the highest level of Cenozoic tuff beds that encircle its base. In the southwestern part of the Jordan Gap quadrangle igneous plugs intruded the Duff formation and the younger tuff beds above the Mitchell Mesa rhyolite. These intrusives may not all be of the same age, but they indicate activity in late Tertiary time; however, they antedate the late faulting. In the Marathon basin numerous small igneous intrusives commonly are closely related to the structure, and King (1937, p. 117) points out that the Tertiary intrusives "appear to have come up along the planes of thrust faults of Paleozoic age". The alignment of the syenite intrusives at Buck Hill and Straddlebug Mountain along the Chalk Draw fault is interesting in this respect, and suggests that the fault along which movement took place in late Tertiary time was an older zone of weakness along which the syenite intrusives were emplaced.

The time of folding and faulting of the Buck Hill volcanic series cannot be demonstrated from the data at hand. It is at least late Tertiary and older than the basin fill and the alluvial deposits of the region. The structural history of Trans-Pecos Texas is complex, and a full understanding will be gained only with solution of some of the larger structural problems which have been summarized by Baker (1934; 1941) and King (1935; 1937).

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 and alluvial deposits indicate that the process has been controlled by temporary base levels, and the present active downcutting indicates recent rejuvenation.

ECONOMIC GEOLOGY

There are no ore deposits in the Buck Hill quadrangle, and there is little local demand for rock aggregate or building stone. A number of tests drilled in exploration for oil and gas in the region have been unsuccessful. Water supply is a local problem in part taken care of by construction of tanks to store the surface run-off for watering cattle. The tanks are earthen or more rarely concrete dams thrown across drainage ways with the storage capacity commonly increased by scooping out a depression. Water also is obtained from wells equipped with windmills. In the northwestern part of the quadrangle the springs which issue from the flows of the Cottonwood Spring basalt have been the main source of water which is piped to the southern part of the area. The water in the Cottonwood Spring basalt has been developed recently by the 02 ranch, and a number of wells up to 300 feet in depth were completed in the area of the basalt south of Mitchell and Crossen mesas. A good well at the Pruett ranch house obtains water from the Walnut Draw fault zone. Water at the Kokernot ranch is drawn from wells in the alluvial gravel.

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Appendix

Detailed Measured Sections

Section No. 1

Section of the Buda limestone and the upper part of the Grayson clay

Measured in the west bank of Calamity Creek at a point 4½ miles south of the Kokernot ranch house.

	Thickness Feet	Thickness Inches
Buda formation:		
17. Limestone, gray, porcelaneous, thick-bedded, brecciated; weathering to a dark-gray etched surface	25	
16. Limestone and marl; limestone, gray, nodular, thin-bedded, fine-grained, fossiliferous; marl, buff to gray, weathering to light tan, fossiliferous. Ammonites, echinoids, etc.	20	
15. Limestone, gray, thick-bedded, brecciated; lower surface undulating	12	
Grayson formation:		
14. Clay, blue-green, brown, red; oxidized along joints and cracks; some thin sandstone layers	2	
13. Clay, green to buff; variegated green, blue, buff, and yellow on weathering; compact to laminated, grading to shale	2	
12. Limestone flags and marl, similar to unit No. 9	5	
11. Marl and clay; weathers to tawny yellow	2	
10. Limestone and marl; limestone gray, weathering white, nodular, contains *Haplostiche texana;* clayey beds tawny yellow with abundant echinoids and *Exogyra*		8–12
9. Limestone and marl; limestone flags, nodular, lenticular, dark gray-blue, sandy weathering to reddish sandy surfaces; marl, sandy and clayey, buff, weathering to light tawny-yellow to reddish buff; erosion leaves ledges of the limestone flags	2	6
8. Marl, sandy, buff, fine-grained, soft, some thin limestone lentils		3–6
7. Clay, green to buff, compact or slightly shaly		6
6. Shell bed; composed almost entirely of *Haplostiche texana* with sandy matrix, weathering to buff and tawny yellow		1–2
5. Sand, shaly, weathers to bright yellow, dull blue and buff; fine-grained, friable		2
4. Clay, light-buff, greenish-yellow, weathering to tawny yellow and variegated colors, forms receding slope	2	2
3. Limestone, flaggy, lenticular, dark gray-blue, medium-grained, sandy, weathering reddish buff		2
2. Shale, light greenish-yellow to olive-green, weathering to very light-buff, grading laterally to sandy limestone flags		3–4
1. Limestone and clay	2	
Total thickness measured	77	
Lower part of Grayson covered.		

Section No. 2

Section of the upper part of the Grayson clay in east bank of large fault gully at southeastern foot of Elephant Mountain

	Thickness Feet	Thickness Inches
Buda formation:		
13. Limestone, gray, fine-grained, nodular; lower surface uneven, undulating	3	

	Thickness Feet	Inches
Grayson formation:		
12. Clay, and shale; alternating brown shale and white clayey material, laminated; weathers dull tannish white		6–8
11. Sandstone, fine-grained, stained reddish		2
10. Shale, tan to brown, weathering to lighter color, laminated		5
9. Sandstone and shale alternating, reddish sand in layers less than 1 inch thick; brownish-red shale	1	3
8. Sandstone and shale with abundant fossils: *Exogyra cartledgei*, *Exogyra whitneyi*, *Ostrea* sp., *Pecten* sp. Shells commonly broken; sand, fine, tan to reddish brown	1	
7. Shale, sandy, brown, fine-grained, laminated	1	3
6. Limestone, gray, nodular, even-textured, slightly sandy near top		6–8
5. Shale and sandstone; thin-bedded, brown, fine-grained, weathers tan, friable		7–9
4. Shell breccia with calcium carbonate cement		2–3
3. Shale, some sand, brown, laminated		8
2. Sandstone, calcareous, fine-grained, well cemented		2
1. Limestone and shale; alternating layers; nodular limestone, very fossiliferous near top with *Inoceramus*, echinoids, and gastropods; weathers to tan and dark buff	4	
Total thickness measured	14	

Section No. 3

Section of the Boquillas formation

Measured in gully on south side of Elephant Mountain 3 miles northeast of the Kokernot ranch house, beginning at small fault just north of water tank.

	Thickness Feet	Inches
Boquillas Formation:		
39. Covered interval, may be Boquillas beneath Pruett tuff	20(?)	
38. Limestone, bluish-gray, fine-grained, a little marl, weathers chalky white	5	
37. Limestone, light-gray to buff, fine-grained, in 1-foot beds separated by marly layers not over 4 inches thick	21	
36. Limestone, light-buff, fine-grained, weathers buff	2	
35. Limestone, fine-grained, slightly nodular beds approximately 1 foot thick separated by thin marly layers, contains *Inoceramus*	8	6
34. Limestone, thick bed, gray to light-buff or tan, very fine-grained, contains small limonite particles, forms overhanging ledge, contains *Inoceramus* fragments	2	6
33. Limestone and marl alternating in 4-inch beds, limestone slightly nodular	2	
32. Limestone, 1-foot beds separated by thin marl layers	5	6
31. Limestone, light-gray with buff tinge, fine-grained, weathers buff to light yellow, contains impressions of *Inoceramus*	2	6
30. Limestone, and marl interbedded; limestone as in interval above, averaging 8–10 inches thick; marl slightly yellow, gray near top	3	
29. Limestone, light-gray to buff, fine-grained	1	
28. Limestone and marly shale, alternating in beds up to 6 inches thick; limestone, gray; marl, buff; *Inoceramus* casts	6	
27. Limestone and marl interbedded in layers averaging 2 inches thick; marl beds more uniform in thickness; colors as above		5
26. Limestone flags and shale alternating, contacts undulating with thickening and thinning, shale weathers to platy structure; flags 2 inches thick, except for 4-inch flag topping interval; banding results from weathering of flags. Many *Inoceramus* casts	8	6
25. Flags and marly shale, alternating as above with 1-foot limestone layer at top of interval, $\frac{1}{2}$-inch layer of *Inoceramus* shell fragments beneath	8	
24. Marly shale with interbedded limestone flags	1	6
23. Flags and shale alternating, bluish-gray flagstones averaging $\frac{1}{2}$ inch thick; shale has pronounced limonitic stains on bedding planes, average 3 inches thick; fossil ice markings on upper shale layers; flags weather dark gray, shales buff	2	

	Thickness Feet	Thickness Inches
22. Marly shale and flags; flags average 1 inch thick, marly layers 3–4 inches; gray to bluish-gray flags weather gray to buff, light-gray marl weathers buff	7	
21. Marly shale and limestone flags alternating, flags $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches thick, gray to dark blue-black weathering gray to buff; marly layers up to 2 inches thick, rather hard, fine-grained, even-textured, weathering light tan and gray	3	
20. Limestone flag, light bluish-gray, very fine-grained, weathering light tan to buff, forms overhanging ledge		4
19. Flags and shaly marl alternating, slightly nodular flags 1–2 inches thick, marl 1–3 inches thick, weathering buff with platy structures	4	
18. Limestone flag, bluish-gray with $\frac{1}{4}$-inch dark blue and green band near top		4
17. Limestone flags averaging 2 inches thick alternating with laminated marl in beds 8–10 inches thick, weathering light tan to yellow with platy structure	8	
16. Limestone flag, light-gray weathering light grayish brown, in places laminated or banded		4
15. Marl and shale with marl predominating, light-gray to white, laminated to thinly bedded	3	8
14. Limestone flag, light-gray, very fine-grained, weathers to dark gray		5
13. Covered, probably thin-bedded limestone and shale	3	6
12. Limestone flag, blue-gray, very fine-grained, sandy; weathers to sandy surface and banded appearance		4
11. Shale and shaly marl, gray to light bluish-gray; weathers with platy structure to light gray or white	3	
10. Flags alternating with shale and thinner limestone layers. Flagstones average about 4 inches thick, shale with limestone layers about 2 inches thick. Shale contains abundant *Inoceramus* prism fragments, commonly stained with limonite	2	6
9. Limestone flag, dark-gray to light-brown, sandy		2
8. Limestone flag, grayish-blue, very fine-grained with little fine sand, some banding, weathers to sandy surface		5–7
7. Shale and thin sandy limestone layers alternating irregularly, very thin-bedded		6
6. Limestone flag, gray, very sandy, in places banding brought out by stains of limonite		4
5. Shale, laminated, light-tan weathering grayish white; minor gray to blue sandy limestone		4
4. Limestone flag, gray, banded, very sandy		6
3. Shale, laminated, tan, sandy		4
2. Limestone flag, gray, banded, sandy, weathers dark gray with rough sandy surface		6
Buda formation:		
1. Limestone, gray, massive, weathers with rough etched surface, very fine-grained, porcelaneous	38	
Total thickness measured	155	

Section No. 4

Partial section of the Pruett formation below the Crossen trachyte

Measured in first gully north of the southeastern end of the Crossen Mesa 2 miles southwest of the Kokernot ranch house.

	Thickness Feet
Pruett formation:	
15. *Crossen trachyte intercalation:* Dark reddish-brown flow of trachyte porphyry with conspicuous columnar jointing	115
14. Covered, in part fresh-water limestone as indicated by float	20
13. Tuff, fine-grained, dove-colored, banded	4
12. Tuff, white, fine-grained, forms receding slope	32
11. Tuff, coarse gray to white beds in less indurated finer-grained ash	81
10. Tuff, gray, massive, forming an overhanging bluff	30
9. Tuff, fine-grained, nodular, hard, blue-gray	146
8. Covered in line of section, tuff	76
7. Tuff, massive, weathering to a rough nodular gravel	24

	Thickness Feet	Inches
6. Covered in line of section, tuff......	20	
5. Tuff, massive, gray to buff with large amount of white ash fragments, hard, weathers to a porous surface..	18	
4. Tuff, gray, fine-grained with small flakes of biotite, massive, weathers to a nodular hard surface, forms an overhanging cliff.................	26	
3. Tuff, extremely hard, dark grayish-blue, dense, weathers to bluish gray.	2	
2. Tuff, similar to unit No. 4..........	9	
1. Tuff, gray to white................	10	
Total thickness measured.......	613	

Base of section covered by alluvium, approximate altitude, 4200 feet.

Section No. 5

Section of the Cottonwood Spring basalt flows and of the upper beds of the Pruett formation in vicinity of elevation 4054 feet south of Cottonwood Spring

	Thickness Feet
Cottonwood Spring basalt:	
16. Basalt flow No. 7; thick, massive basalt capping mesa and forming high cliff in southern scarp. Upper amygdaloidal part 20 feet thick grades down to coarse-grained basalt. Fresh color reddish gray weathering to gray and yellowish brown. Lower part of flow forms slope with only scattered outcrops and with abundant ocotillo. Vesicular flow breccia at base...........	164
15. Tuff, light-gray to red; red rock is hard, dense, baked tuff with subconchoidal fracture. Basalt fragments roughly rounded in lower 1–2 feet of gray to pink tuff. Basalt is vesicular and in pieces up to 4 inches in diameter.....................	8–19
14. Basalt flow No. 6; massive, weathering with slabby structure in upper part and spheroidally in lower part; upper part is 14-foot thick amygdaloid...........................	46–51
13. Basalt flow No. 5; upper 6 feet amygdaloidal with fillings of calcite and chalcedony; lower part massive, uniform.......................	10–12
12. Basalt flow No. 4; amygdaloidal top about 4 feet thick, reddish-gray; lower part, dense basalt...........	12–13
11. Basalt flow No. 3; amygdaloidal top 2½ feet thick with abundant fillings of chalcedony and of agate with small quartz crystals in cavities at centers of fillings. Base of flow is flow breccia, 2 feet thick; middle part, dense and uniform...........	6– 9
10. Basalt flow No. 2; vesicular top with amygdules of chalcedony, calcite, abundant red and yellow jasper.	6–15
9. Basalt flow No. 1; basal flow of the Cottonwood Spring basalt; upper 9 feet amygdaloidal reddish-brown, ropy (pahoehoe), with many fillings of calcite, chalcedony, and agate. Green chloritelike coating on basalt in cavities and around amygdules; fillings of agate commonly terminated inward with small quartz crystals. Lower part of flow is massive and forms prominent bench or ledge 3–4 feet thick of coarse-grained, black basalt with plagioclase needles aligned in flow structure. Flow is badly weathered, but fresh samples are available from heavy ledge and from large boulders. Analyzed specimen No. 840, Table 7, No. 2.......	42–50
Pruett formation:	
8. Tuff, gray to reddish-brown with conspicuous light-gray to white mottling, even earthy fracture, baked to hard, reddish-brown rock with subconchoidal fracture immediately below basalt flow; contact with overlying basalt sharp and distinct..........................	48
7. Tuff, gray to pink, thin-bedded with upper beds somewhat thicker than lower ones, indurated.............	16
6b. *Breccia-conglomerate:* massive ledge, 5½–6 feet thick, corresponds to 6a below. Section was offset at this point. Beds from 6a and down were measured below elevation 4054; beds from 6b and up were offset approximately 400 feet to the west....	
6a. Massive breccia and conglomerate of igneous rock pebbles and fragments capping spur at elevation 4054′ south of Cottonwood Spring and continuing eastward to Whirlwind Spring and westward into the Jordan Gap quadrangle. Fragments generally 0.1–0.2 inch across but many larger up to boulders of 1 foot or more in diameter. Chiefly igneous rock fragments with some chert and banded red and yellow jasper in a gray to yellow matrix of volcanic ash, locally calcareous. Weathers to a porous nodular, yellow to dark-brown ledge commonly covered with ocotillo. Varies laterally both in thickness and in size of component fragments, but is a prominent ledge maker and horizon marker........................	2
5. Volcanic ash, gray to light-yellow, roughly bedded, and essentially one	

	Thickness Feet
massive layer; fine-grained, with rough uneven fracture, weathers to dark yellow brown...............	13
4. Tuff, purplish-gray, hard, brittle, banded........................	1
3. Ash, pink to reddish, mottled with white, weathers to a smooth slope...	23
2. Ash, gray to red, poorly bedded, in part well lithified. Beds from 6 inches to 1 foot thick. Alternation of indurated and softer beds produce a step-like appearance in outcrop....	7
1. Ash, gray to red, weathers to smooth slope usually covered with débris....	16
Total thickness measured.......	437

Thickness of the Cottonwood Spring basalt, 300± feet.
Base of section, 3992 feet above sea level.

Section No. 6

Section of the Sheep Canyon basalt flows

Measured by G. C. Hardin, Jr., in Sheep Canyon, Alpine quadrangle.

	Thickness Feet
Cottonwood Spring basalt:	
12. Basalt flow, amygdaloidal at top, oxidized and badly weathered......	33
11. Basalt flow, amygdaloidal at top, thin flow breccia at base..........	98
Pruett formation:	
10. Tuff, pink at base and blood red near top........................	3
9. *Potato Hill andesite intercalation:* Massive porphyritic andesite near base; upper 30–40 feet flow breccia..	72
8. *Sheep Canyon basalt intercalations:* Porphyritic basalt flow No. 4.......	28
7. Tuff, light-pink grading to light green..........................	4.5
6. Porphyritic basalt flow No. 3; amygdaloidal near top; phenocrysts locally segregated (glomeroporphyritic)........................	42.5
5. Fresh-water limestone, light-gray to white, tuffaceous................	6
4. Basalt flow No. 2; coarse even-grained with a few phenocrysts, amygdaloidal near top...........	32
3. Tuff with very thin lenticular beds of fresh-water limestone...........	5.5
2. Basalt flow No. 1; dense, even-grained, amygdaloidal near top. Possibly more than one flow as section is partially covered with talus..	131
1. *Fresh-water limestone:* dense, gray, massive, tuffaceous limestone......	
Total thickness measured.......	455.5

Section No. 7

Section at Hill 4975 on Crossen Mesa

	Thickness Feet
Cottonwood Spring basalt flows:	
11. Basalt flow No. 6; dense, black basalt with prominent flow breccia at base...........................	55
10. Tuff, red, dense, hard, baked.......	7
9. Basalt flow No. 5, amygdaloidal at top...........................	7
8. Basalt flow No. 4, amygdaloidal at top grading down to coarse-grained basalt, weathers to yellowish brown.	16
7. Basalt flow No. 3, amygdaloidal at top with blowholes ½ inch or more across, fillings of calcite and chalcedony........................	11
6. Basalt flow No. 2, amygdaloidal at top 2–3 feet thick................	15
5. Basalt flow No. 1, amygdaloidal at top about 14 feet thick; fine-grained, somewhat vesicular flow breccia at base about 12 feet thick...........	61
Pruett formation:	
4. Tuff, grayish-white, fine- to medium-grained........................	26
3. *Potato Hill andesite intercalation:* porphyritic andesite flow, red residual material and weathered vesicular andesite at top, upper part of flow altered green, many amygdules of chalcedony; grades down to reddish-brown vesicular andesite flow breccia which weathers to greenish and yellowish-brown boulders. Massive andesite at base of flow with numerous plagioclase phenocrysts up to 1 inch in length and ½ inch across. Ocotillo common on weathered slopes of andesite. Analyzed specimen No. 812, Table 6........................	40
2. Tuff, light yellowish-gray to greenish-gray with numerous light-gray fragments. Analyzed specimen No. 813, Table 2, No. 1..............	37
1. *Crossen trachyte intercalation:* porphyritic trachyte flow with many stubby feldspar phenocrysts in a dense red groundmass...........	
Total thickness measured.......	275

Base of measured section, 4699 feet above sea level.

Section No. 8

Section of the Duff tuff measured in largest gully on south slope of Mitchell Mesa

	Thickness Feet
Mitchell Mesa rhyolite:	
24. Rhyolite porphyry, phenocrysts of quartz and glassy sanidine in dense to vesicular grayish-pink groundmass	38
Duff formation:	
23. Covered in line of section, tuff	64
22. Tuff, white, massive, fine-grained	35
21. Tuff, gray to buff and light-brown, roughly bedded and cross-bedded, medium-grained	104
20. Conglomerate, well-rounded pebbles in matrix of coarse tuffaceous sand	8–10
19. Tuff, gray to light-buff, cross-bedded, fine-grained	46
18. Conglomerate, gray, roughly bedded and cross-bedded; pebbles, cobbles, and boulders up to 1 foot in diameter, mainly of igneous volcanic rocks ranging from rhyolite to basalt, some of vesicular lava, commonly well rounded. In places cobbles about 6 inches in diameter are well sorted with little or no matrix material	6–8
17. Tuff, light-buff to reddish-brown, locally gray; medium-grained, bedded in layers 4–6 inches thick; stands with vertical front	105
16. Tuff, grayish-white with several 6-inch beds of brownish-red stained ash, fine- to medium-grained, massive	123
15. Tuff, stained light brownish red, with small white spots, coarse- to medium-grained, forms a prominent bench	4–6
14. Tuff, gray with several 6-inch to 1-foot reddish-buff beds near top, fine- to medium-grained, massive and holds a steep face on scarp; weathers to small nodular forms. Many thin clastic dikes of dark-gray to buff-colored sandy ash cut this unit	238
13. Tuff, buff to light-brown, medium-grained	2–4
12. Tuff, gray, fine-grained, massive, cut by many small brown, gray and varicolored clastic dikes	29
11. Tuff, buff, coarse-grained; forms benches; grades laterally to a thin breccia	3
10. Tuff, light- to dark-gray, fine-grained, weathers to a nodular, concretionary surface; stands in steep faces and forms benches	125
9. Tuff and breccia, dark-buff with small white ash flecks; forms a flat surface on weathering	3
8. Tuff, light-gray, fine-grained, uniform, massive, nodular on weathering	17
7. Volcanic breccia, light- to dark-buff, with fragments several millimeters across in fine-grained ash matrix. Forms ledge and overhanging layer	2–3
6. Tuff, light-gray to tan, in most places peppered with flakes of biotite, weathers to nodular surface, in places cut by clastic dikes	53
5. Conglomerate, generally stained brown, great range in size of component pieces which are largely volcanic igneous rocks, from small pebbles to boulders 6 feet across. Matrix commonly cross-bedded coarse sandstone. In the line of section this conglomerate bed is relatively thin, but in places it is up to 30 feet thick	6
4. Tuff, dark-gray to buff, very coarse, roughly bedded and cross-bedded, grades to sandstone in places	20
3. Tuff, gray, fine-grained, massive, weathers to a porous honeycombed surface. Forms vertical face, commonly undercut	9
2. Covered in line of section, tuff	8
Cottonwood Spring basalt:	
1. Basalt flow, fine-grained, very vesicular at top	5
Total thickness measured	1058

Section No. 9

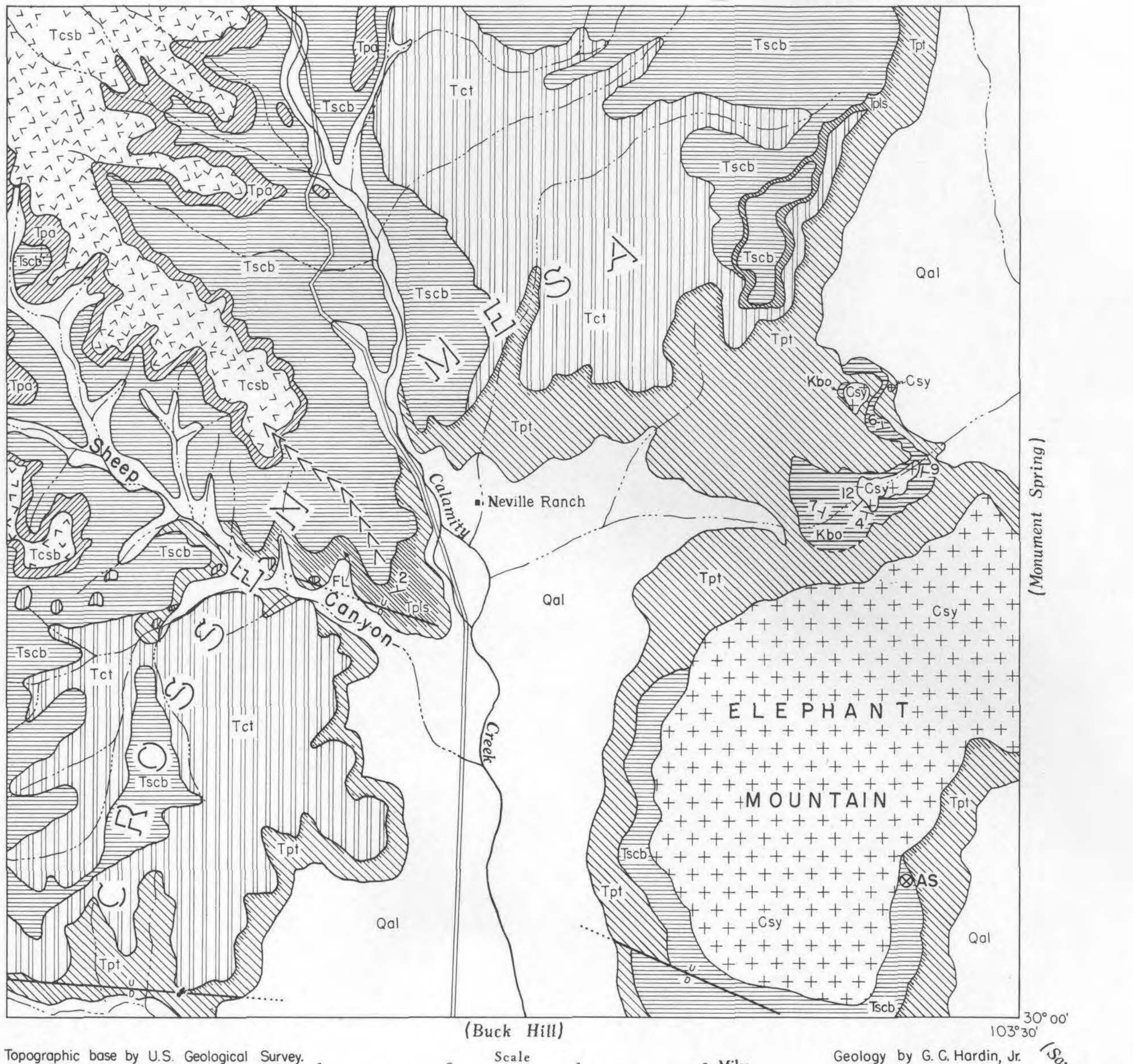
Section of Sheep Canyon basalt flows and Pruett tuff

In gully west of first large fault northeast of the Kokernot ranch house on the southern slope of Elephant Mountain.

	Thickness Feet
12. Covered interval, may possibly be basalt	50
11. *Sheep Canyon basalt intercalation:* basalt porphyry flow, black, weathering to rusty brown. Vesicular with openings in part filled with calcite, vesicles elongated in direction approximately N. 65° W.	171
10. *Sheep Canyon basalt:* porphyritic flow, upper 20–30 feet vesicular and amygdaloidal with fillings of jasper, chalcedony, and calcite. Abundant glassy, green, plagioclase phenocrysts up to 1 inch in length. Lower	

	Thickness Feet
part of flow is massive, weathering spheroidally. Gray, medium-grained tuff occurs between this flow and the upper basalt in some places.	121
9. Fresh-water limestone, light-gray, very fine-grained, in beds 1–2 feet thick. Weathers to chalky white, forms prominent ledges. Gastropods and shell fragments in part silicified. Thickness variable; may be as much as 13 feet	4
8. *Sheep Canyon basalt:* porphyritic flow, vesicular in upper half with many calcite amygdules. Limestone above flow contains pebbles of basalt and extends down filling crevices and openings in upper part of flow	88
7. Covered interval, probably tuff	83
6. Tuff, hard, well-indurated, gray to white, fine-grained, maintains vertical faces	70
5. Tuff, indurated, light-gray, medium-grained	10
4. Tuff, hard, gray to light-yellow	32
3. Conglomerate, chert and hard tuff pebbles	4.5
2. Tuff, hard, gray, uniform	8
1. Tuff, gray to pink or purplish, massive, weathers to nodular, pebbly surface. Some pebbles of dense gray limestone. Molds of low-spired fresh-water snails	84
Total thickness measured	725.5

Base of section covered by alluvium.



Topographic base by U.S. Geological Survey.
Surveyed in 1893.
Edition of 1895.

Geology by G. C. Hardin, Jr.
Surveyed in 1941.

EXPLANATION

QUATERNARY

Qal

Alluvium

CENOZOIC

Csy

Intrusive syenite

TERTIARY

Tcsb

Cottonwood Spring basalt

Tpa
Tscb
Tct
Tpls
Tpt

Pruett tuff formation

(Volcanic tuff breccia, and (Tpls) fresh-water limestone member; intercalated flows: (Tpa) Potato Hill Andesite, (Tscb) Sheep Canyon basalt; (Tct) Crossen trachyte)

UNCONFORMITY

UPPER CRETACEOUS

Kbo

Boquillas formation

6

Strike and dip of beds

U D

Normal Fault

(U, uplifted side; D, downthrown side, line solid where known; dotted where inferred under cover of alluvium)

FL

Fossil locality

Line of measured section
(Appendix, No. 6)

⊗AS

Analyzed sample
(Table 5, No. 3)

GEOLOGIC RECONNAISSANCE MAP OF THE ELEPHANT MOUNTAIN AREA, BREWSTER COUNTY, TEXAS.