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Geology of Cathedral Mountain Quadrangle, Brewster County, Texas

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GEOLOGY OF CATHEDRAL MOUNTAIN QUADRANGLE, BREWSTER COUNTY, TEXAS

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ABSTRACT

Rocks exposed in the Cathedral Mountain quadrangle in the southeastern Davis Mountains of Trans-Pecos Texas are assigned to the Word formation and to Capitan limestone in the Permian Guadalupe series; to the Maxon sandstone, Edwards limestone, Georgetown limestone, and Grayson (Del Rio) marl in the Cretaceous Comanche series; to the Buda limestone and Boquillas limestone in the Cretaceous Gulf series; and to the Buck Hill volcanic series in the Tertiary. Volcanic rocks up to 4600 feet thick cover most of the quadrangle. The volcanic succession, similar to that in Buck Hill and other quadrangles to the south, is divided into the Pruett tuff, Crossen trachyte, Sheep Canyon basalt, Potato Hill andesite, Cottonwood Spring basalt, Duff formation, and Rawls basalt. Vertebrate fossils indicate a late Eocene (Duchesne) age for the Pruett tuff (restricted to the lowermost tuff, sandstone, and conglomerate beds). The top of the Eocene is placed at a prominent disconformity between the Crossen trachyte and the Sheep Canyon basalt; it is suggested the overlying lava and tuff layers are Oligocene and younger (?). Some of the many intrusive bodies of alkalic microsyenite which are younger than the volcanic rocks have effected much local deformation of the layered rocks. Quaternary alluvium is present along streams and over valley flats.

Northward across the quadrangle, the Crossen trachyte gains appreciable quartz, the Potato Hill andesite changes from highly porphyritic to nonporphyritic, and the Duff formation changes from dominantly rhyolite tuff to lava, tuff, and conglomerate (Decie member). Effects of five crustal disturbances—mid-Mesozoic, late Cretaceous, pre-upper Eocene, and three in the late Cenozoic—are apparent. Differential erosion of the intruded, folded, and faulted volcanic succession has roughened and diversified the landscape.

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INTRODUCTION

Location

The Davis Mountains in Trans-Pecos Texas lie at the intersection of Appalachian and Laramide lines of folding, across the connecting channel between the Permian Marfa and Delaware basins at the northern edge of the Mesozoic Coahuila peninsula between the Basin and Range and the Mexican Highlands physiographic provinces.

The Cathedral Mountain quadrangle (Fig. 1), an area of about 225 square miles in the southeastern part of the Davis Mountains, is the location under investigation. It is in northwestern Brewster County; the northern boundary is about 6½ miles south of Alpine (population 5000), county seat of Brewster County. State highway No. 118, from Alpine to Big Bend National Park, extends north-south near its eastern boundary. It is the southeastern quadrangle of the 30-minute Alpine quadrangle which has been divided by the U. S. Geological Survey into four 15-minute quadrangles—named Alpine in the northeast, Paisano Peak in the northwest, and unnamed in the southwest. In the text, the two Alpine quadrangles are designated as Alpine (30-min.) quadrangle and Alpine (15-min.) quadrangle.

Scope of Work

King studied the Glass Mountains (1930), outlined the structural development of Trans-Pecos Texas (1935), and mapped the Marathon and Monument Spring quadrangles (1937). Work by Lonsdale (1940) was the first comprehensive study of the igneous geology of Trans-Pecos Texas. Eifler mapped the Santiago Peak quadrangle (1943) and the Barrilla Mountains (1951). Goldich and Elms (1949) made a valuable contribution by working out the volcanic sequence in the Buck Hill quadrangle, and Goldich and Seward (1948) studied the northern part of the Jordan Gap quadrangle. Other recent workers in this region include R. R. Bloomer (1949, Ph.D. Dissertation, Univ. Texas) in the Christmas and Rosillos mountains, G. M. Stafford (open-file manuscript, 1952) in the Nine Point Mesa quadrangle, Erickson (1953) in the Tascotal Mesa quadrangle, Moon (1953) in the Agua Fria quadrangle, C. C. Rix (1953, Ph.D. Dissertation, Univ. Texas) in the Chinati Mountains, and Graves (1954) in the Hood Spring quadrangle.

Eighteen weeks were spent in the field mapping the Cathedral Mountain quadrangle—6 weeks each summer during 1949, 1950, and 1951. Approximately 6 weeks of reconnaissance mapping was done in the Alpine (15-min.) quadrangle in the spring of 1950 in connection with a ground-water survey for the city of Alpine (Fig. 2). All mapping was done on United States Air Force aerial photographs. The petrographic work and preparation of the manuscript were done at The University of Texas during the academic year 1952–53. The project is part of a West Texas region program of the Bureau of Economic Geology, The University of Texas.

ACKNOWLEDGMENTS

Dr. S. S. Goldich, formerly with the Bureau of Economic Geology, interested the writer in the problem and gave valuable assistance and encouragement. A better understanding of field relationships resulted from discussions in the field with Dr. J. T. Lonsdale, Director of the

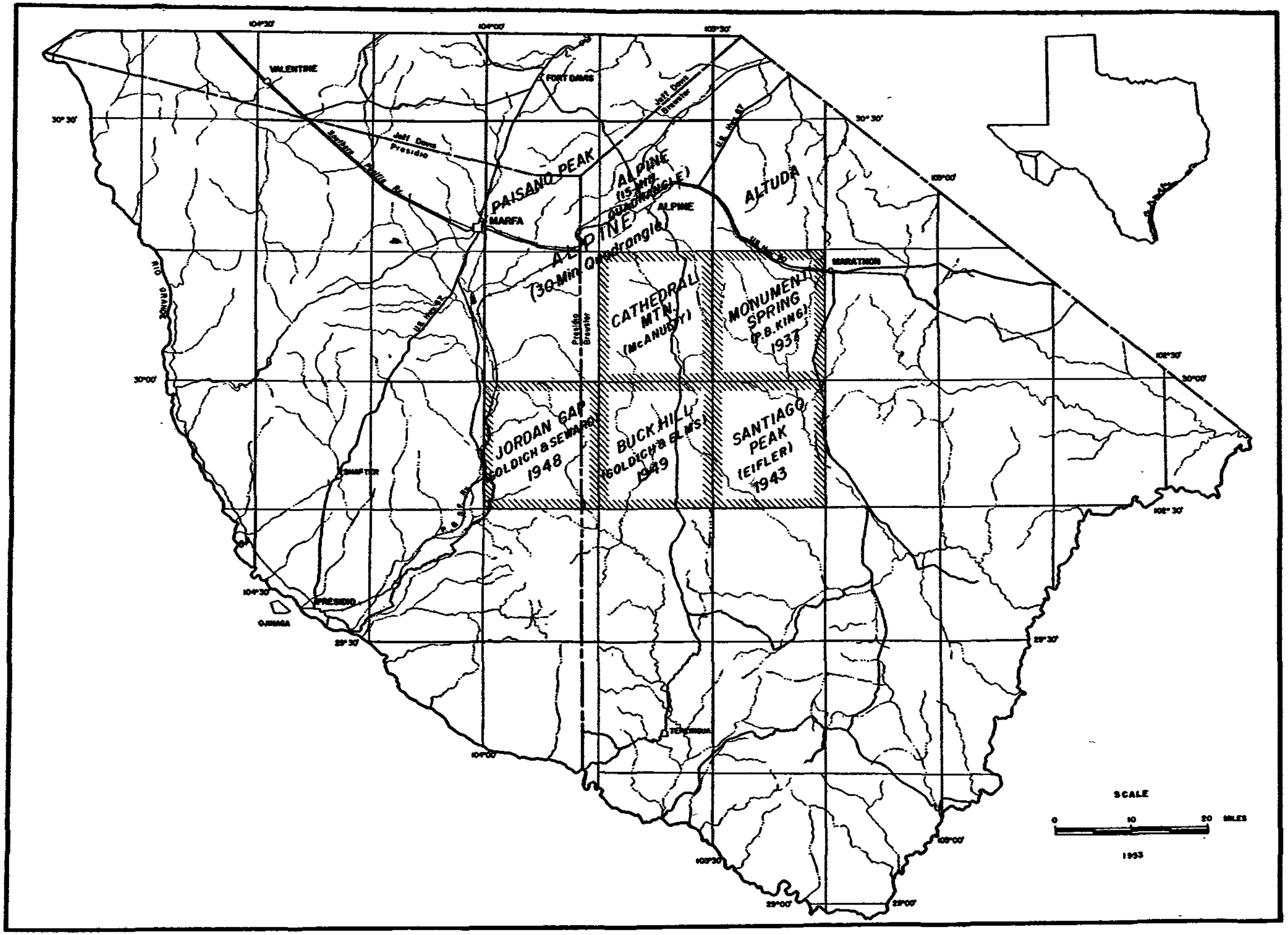


FIGURE 1.—INDEX MAP OF TRANS-PECOS TEXAS SHOWING LOCATION OF CATHEDRAL MOUNTAIN QUADRANGLE AND ADJOINING AREAS OF PUBLISHED MAPS

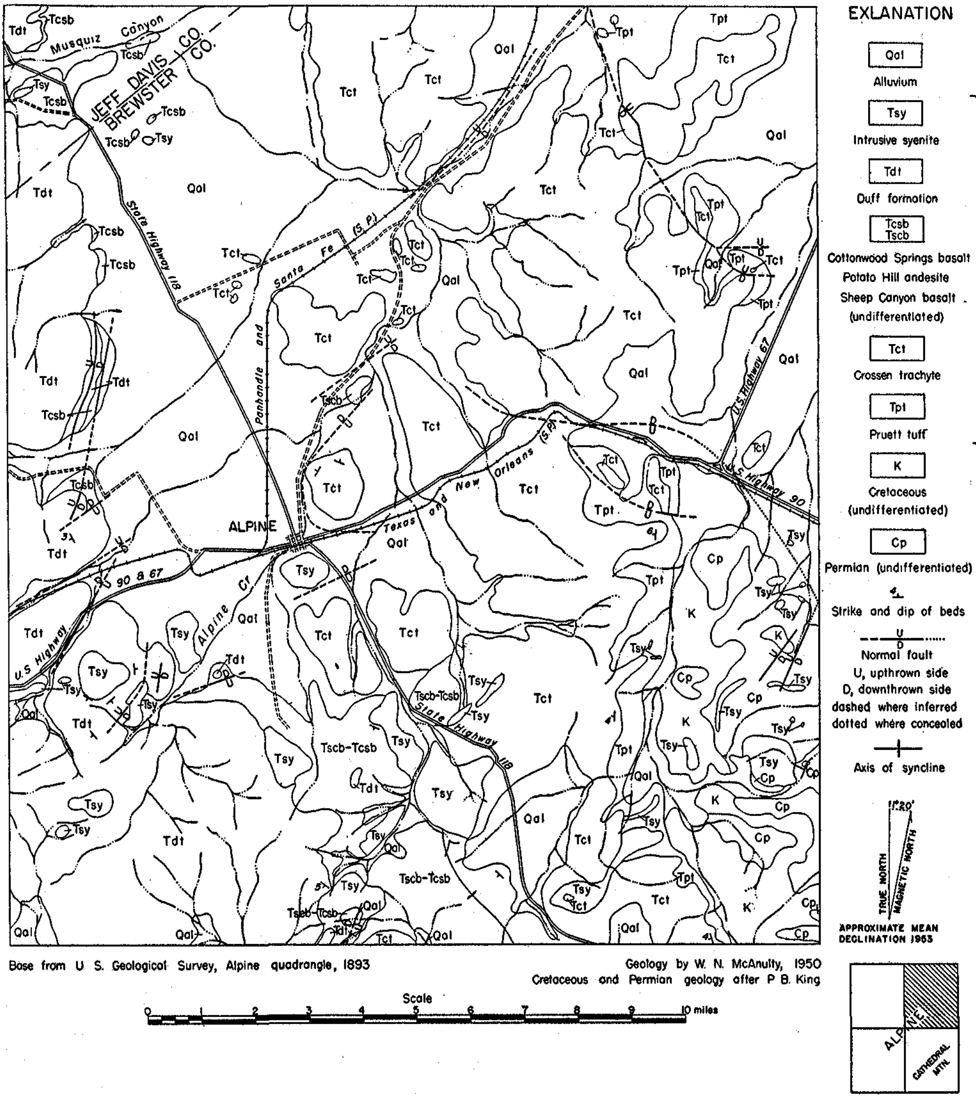


FIGURE 2.—GEOLOGIC RECONNAISSANCE MAP OF THE ALPINE (15-MIN.) QUADRANGLE, BREWSTER COUNTY, TEXAS

Bureau of Economic Geology, and Professor R. K. DeFord, The University of Texas.

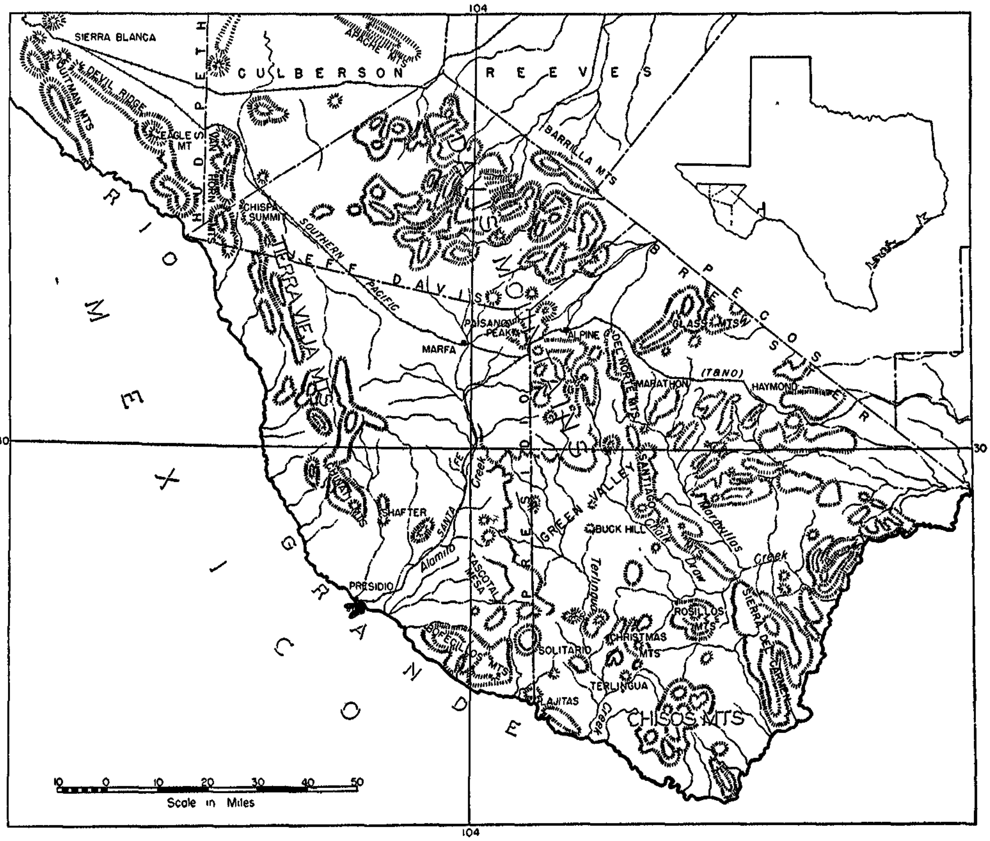
Special credit is due Dr. S. E. Clabaugh, The University of Texas, for assistance in the petrographic studies, and for many helpful suggestions for the manuscript. Able assistance in the field was given by Frank Woodward, Jr., in 1949, Dennis R. Taylor in 1950, and Robert L. Wilson in 1951. David L. Amsbury helped identify the Cretaceous fossils.

Appreciation is expressed to the following ranchers and landowners in the area for their hospitality and co-operation: Messrs. W. L. Kokernot, Nevill Haynes, James Anderson, Frank Woodward, Sr., Ray Willoughby, Gay Merriwether, Zeb Decie, and W. C. Crossen, and to Mrs. Brown, Mrs. Clark, and Mrs. Crossen.

The manuscript, presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The University of Texas, May 1953, was reviewed by the graduate faculty

members of that university, R. K. DeFord, J. T. Lonsdale, S. E. Clabaugh, S. P. Ellison, and D. D. Brand. It was read also by Dr. S. S. Goldich of the University of Minnesota.

Basin and Range province, on the northeast and east by the Great Plains province, and on the west by the western branch of the Sierra Madre Oriental of the Mexican Highlands province.



FIGUEE 3.—SKETCH MAP of A PART OF TRANS-PECOS TEXAS SHOWING PRINCIPAL PHYSIOGRAPHIC FEATURES

The Bureau of Economic Geology financed the field work, cost of thin sections, and drafting of the geologic maps. A scholarship granted by the Standard Oil Company of Texas made possible the residence work at the University.

REGIONAL SETTING

The Davis Mountains occupy an irregularly shaped area of approximately 1400 square miles in Jeff Davis, Brewster, and Presidio counties in west-central Trans-Pecos Texas. They lie at the north end of the Eastern Border Ranges division of the Mexican Highlands physiographic province (King, 1937, p. 2), which is bordered on the northwest by the Along the east side of the southern Davis Mountains are the Del Norte Mountains, which together with the Santiago Mountains to the south form the west side of the Marathon dome. These segments and the Sierra Del Carmen constitute a narrow, continuous range composed largely of folded and faulted Cretaceous limestone trending southwestward into northern Mexico.

The Davis Mountains are a highly dissected erosional remnant of a vast volcanic field that originally may have covered several thousand square miles in Trans-Pecos Texas and northern Mexico. During the Tertiary the thick volcanic succession accumulated in the northeastern part of an extensive structural depres-

TABLE 1.—GEOLOGIC FORMATIONS IN CATHEDRAL MOUNTAIN QUADRANGLE

Age	Group and Formation		Thickness (feet)	Lithology and Remarks
Quaternary	Alluvium		30±	Pleistocene and Recent valley fill and alluvium; unconsolidated silt, sand, and gravel
Tertiary	Buck Hill volcanic series	Rawls basalt	30–545	Very fine-grained, porphyritic flows of trachybasalt; massive, coarse flow breccia zones
		Tascotal formation	50–462	Light-gray and yellow rhyolitic tuff, coarse-grained sandstone and conglomerate
Oligocene and younger (?)		Mitchell Mesa welded tuff	58–134	Pink to gray, welded rhyolitic tuff
		Duff formation	1400–1500	Rhyolitic tuff, minor sandstone and conglomerate, two thin basalt flows in southern half; considerable sandstone, conglomerate, and thick basic and acidic lavas and flow breccias in north
		Cottonwood Spring basalt	220–332	Dense to vesicular and amygdaloidal flows of trachyandesite and olivine basalt; thick flow breccias
		Potato Hill andesite	35–190	Dark reddish-brown to gray porphyritic and nonporphyritic flow and flow breccia
		Sheep Canyon basalt	0–454	Porphyritic basaltic and trachyandesitic flows, separated by thin interbeds of tuff and fresh-water limestone
Upper Eocene (Duchesne)		Crossen trachyte	0–265	Massive flow of porphyritic trachyte
		Pruett tuff	474–798	Rhyolitic tuff, with sandstone, conglomerate, and considerable fresh-water limestone

Angular unconformity

TABLE 1.—*Continued*

Age	Group and Formation		Thickness (feet)	Lithology and Remarks
Cretaceous Gulf series	Eagle Ford group	Boquillas formation	0–75	Alternating shale and limestone flags
		Disconformity		
Comanche series	Washita group	Buda limestone	60–70	Thick-bedded limestone, with middle nodular marly member
		Disconformity		
		Grayson marl	10–20	Calcareous clay and marl, with flaggy sandy limestone
		Georgetown limestone	200±	Thick-bedded limestone, more thinly bedded in upper part
	Fredericksburg group	Edwards limestone	250±	Dense to marly, thin- to thick-bedded, cherty limestone
	Trinity group (?)	Maxon (?) sandstone	366±	Sandstone, shale, and conglomerate
Permian Guadalupe series	Capitan limestone		120±	Massive dolomitic limestone
	Word formation		1500±	Siliceous shale, sandstone, conglomerate, and thin-bedded limestone

sion bounded on the north by the Apache-Delaware Mountain uplift and on the east by the Marathon dome, and has subsequently been carved by differential erosion into a rugged mountainous terrain (Fig. 3).

STRATIGRAPHY

Permian System

General.—The most nearly complete, continuously exposed marine Permian section in North America is in the Glass Mountains, a few miles northeast of the Cathedral Mountain quadrangle. The upper part of the Permian system is exposed in the Del Norte Mountains; two formations (Word formation and Capitan limestone) outcrop near Mt. Ord in the northeast corner of the Cathedral Mountain quadrangle. The Del Norte-Glass Mountains Permian stratigraphy is complicated by facies changes—forereef to reef to backreef from southwest to northeast, respectively; the strata of the Del Norte Mountains were laid down in a forereef environment.

A study of the complex Permian stratigraphy in the Del Norte and Glass Mountains is a problem beyond the scope of this investigation. The writer's work on it was restricted to mapping the outcrops and a field examination of the lithology in the immediate vicinity of Mt. Ord. Detailed maps, cross-sections, and excellent discussions of the Permian in this region are contained in papers by King (1930, 1937, 1942).

Word formation.—In the Del Norte Mountains the Word formation reaches a thickness of about 1500 feet, but only the upper 325 feet is exposed in the Cathedral Mountain quadrangle. It contains limestone but is mostly siliceous shale, sandstone, and conglomerate. The lower limestone units contain abundant *Parafusulina* as well as a brachiopod fauna (King, 1937, p. 102). No fossils were found in the upper part of the formation. The Word formation is early Guadalupian and is equivalent to the Brushy Canyon and Cherry Canyon formations of the Guadalupe Mountain (Adams *et al*, 1949, p. 8).

Section of Word formation exposed in canyon wall about 3/4 mile northeast of Mt. Ord

	Thickness (Feet)
Light-gray, fine-grained, thin-bedded dolomitic limestone containing small chert nodules, and interbedded siliceous shale........	50
Light-brown, fine-grained, thin-bedded, argillaceous sandstone, and siliceous shale.......	85
Brown platy siliceous shale, with thin interbeds of dense limestone..................	90
Light reddish-brown, fine-grained, flaggy sandstone with interbedded siliceous shale......	100
Total exposed thickness	325

Capitan limestone.—In the Mt. Ord area 120 feet of light-gray, massive dolomitic limestone conformably overlies the Word formation. Udden (1917, p. 50–52) placed this limestone in the lower part of his Vidrio formation. Stratigraphic terminology for west Texas Permian rocks has undergone several revisions, and the following names apply to this unit: "lower massive member" of the Capitan formation (King, 1930, p. 78), "Vidrio massive member" of the Capitan limestone (King, 1937, p. 105), and "Vidrio" (Adams *et al.*, 1949, p. 6). On the basis of fusulinid *Polydiexodina* in the rock, the writer mapped it as Capitan limestone.

An angular unconformity separates the Capitan limestone from the overlying Edwards limestone of Cretaceous age in this part of the Del Norte Mountains.

Cretaceous System

General.–All exposures of Cretaceous rocks are either at the base of the easternmost and southernmost erosional escarpments of the volcanic rocks or around laccolithic intrusions. The distribution of these exposures indicates that Cretaceous rocks probably underlie the Tertiary volcanic rocks throughout the quadrangle. The Cretaceous rocks are exposed more extensively in the Del Norte Mountains immediately to the east, in the escarpments flanking the Marathon dome, and in the region south of the Cathedral Mountain quadrangle.

The Boquillas limestone (Table 1) thins northward because of erosional truncation. Northernmost outcrops are discontinuous erosional remnants, whereas at the southern edge of the quadrangle the formation is much thicker and seems continuous. Beds between the Boquillas and the first lava flow, between the Del Norte Mountains and the Mt. Ord escarpment, are tuff and tuffaceous sedimentary rocks including beds of nonmarine limestones in the Pruett tuff. King (1937, p. 116) considered them equivalent to the Austin chalk or younger Cretaceous formations.

Maxon (?) sandstone.—The development of Cienega Mountain, a "trapdoor dome" type of laccolith in the west-central part of the quadrangle, produced several hundred feet of structural relief by arching Cretaceous strata and Tertiary volcanic rock over the central dome and on the northern and western margins. Except for one small knoblike remnant of sandstone and conglomerate at the southeast margin and a narrow arm of the same material ending in a peak on the northern edge, the original cover over the summit has been eroded to expose the syenite core. As the basal conglomeratic sandstone dips steeply away from the narrow northern summit, the outcrop widens down the north and west slopes, forming prominent curving cuestas trending down the slopes on the northwest and northeast. The conglomeratic sandstone is overlain by tilted Cretaceous limestone on the north and northwest, which in turn is overlain by Tertiary volcanic rock and alluvium along the west side of the mountain.

The lower part of the basal conglomeratic sandstone is exposed only rarely on the steep, debris-covered, upper slopes of the narrow summit ridge on Cienega Mountain; the upper portion is fairly well exposed in the inface of the cuesta swinging down and around the lower slopes. Poor exposures and the flexed attitude of the beds conforming to the domical shape of the syenite core make it difficult to ascertain true thickness. The dip steepens from 8° in the summit area to about 18° on the lower slopes. As measured with a hand level and corrected for changing dips, the thickness is 366 feet.

The lower 300 feet is light-gray, fine-grained, well-cemented quartz sandstone, containing thin beds of gray, slightly calcareous argillaceous sandstone and arenaceous shale, and lenses of medium- to very coarse-grained quartz sandstone and granule-and-pebble quartz conglomerate. Numerous pea-sized quartz and chert pebbles are scattered through the shaly layers. The upper 66 feet consists mostly of gray to pink, medium- to very coarse-grained, well-cemented quartz sandstones and granule, pebble, and cobble quartz conglomerate. Conglomeratic lenses are most numerous and coarser in the upper part; the lower portion contains more fine-grained sandstone and argillaceous material. In the conglomerate the granules, pebbles, and cobbles of white vein quartz, brown quartzite, and black and varicolored chert are well rounded.

No fossils were found in this formation. It is assigned to the Cretaceous because it is beneath Cretaceous limestone, and because basal Cretaceous conglomeratic sandstone is known in the Del Norte and Glass mountains and in the Solitario. There is little reason to doubt that these beds are Cretaceous, but whether they are Fredericksburg or Trinity is undetermined.

At Mt. Ord, Permian limestone underlies Edwards limestone. Near Black Peak, a few miles to the southeast in the Del Norte Mountains, the Edwards rests on cross-bedded conglomeratic sandstone, which grades southeastward into marly limestone containing Walnut and Comanche Peak (Fredericksburg) fossils. This suggests a Fredericksburg age for the basal conglomeratic sandstone at Cienega Mountain, but in the Glass Mountains lithologically similar beds are laterally continuous with the Maxon sandstone which King (1937, p. 114) placed at the top of the Trinity group. The Cienega Mountain section is thicker than basal beds in the neighboring areas, but perhaps this thickening should be expected immediately west of the Marathon dome, an area probably topographically and structurally low during the first inundation by the Cretaceous sea. The Cienega Mountain section may be partly Trinity and partly Fredericksburg in age.

Edwards limestone.—The 248-foot-thick Edwards limestone, exposed near Mt. Ord in the extreme northeast corner of the Cathedral Mountain quadrangle, is composed of light-gray, dense to marly, thin- to thick-bedded limestone separated by thin layers of soft marl. The limestone beds contain much brown, nodular chert; various types of rudistids and chamids occur in the more massive strata. At the base of the formation is a thin (less than 1 foot) limestone conglomerate. In this vicinity and northward in the Del Norte and Glass mountains, the Edwards contains more marl and marly limestone and has a less reefy appearance than in the Del Norte and Santiago mountains on the southeast. Near Mt. Ord and in the northern Del Norte Mountains the Edwards rests on the Capitan limestone and is overlain by Georgetown limestone.

Overlying the basal Cretaceous conglomeratic sandstone on the north and northwest slopes of Cienega Mountain is approximately 425 feet of metamorphosed, marine fossiliferous limestone assigned to the Edwards and Georgetown formations. It is about as thick as the combined Edwards and Georgetown near Mt. Ord. The beds are tilted 12°–18° away from the Cienega Mountain laccolith. On the northeast and east, where the limestone is in contact with the Cienega Mountain syenite mass, two bosses on the large intrusion cut the limestones in the central part of the outcrop area. Contact metamorphic effects range from slight baking effects to dark coarsely crystalline marble and friable sugary limestone.

The lower 250 feet of the section equivalent (?) to Edwards consists of light-gray to black (in places mottled), finely crystalline limestone in beds a few inches to 4 feet thick, separated by thin layers of yellowish marl. Considerable chert, in the form of narrow stringers, irregular-shaped nodules, and thin discontinuous layers along bedding planes, occurs in the limestone beds, and narrow calcite veins are numerous along joints and fractures. The limestone strata are highly fossiliferous but so altered that it is practically impossible to collect identifiable specimens.

Georgetown limestone.—Around Mt. Ord the Georgetown limestone ranges from 210 to 253 feet in thickness and is composed of buff to gray, fine- to coarse-grained, nodular and marly, fossiliferous limestone in beds a few inches to a few feet thick. Two massive members, one near the middle and one toward the top, tend to form prominent ledges. King (1937, p. 115) suggested that these two ledge-making members correlate with the "middle cap rock" and "upper cap rock" of the Fort Stockton district, and Adkins (1927, p. 57–58) suggested that the lower member is "of approximately Denton age" and that the upper one could be correlated provisionally with the Main Street of central Texas. The upper massive member contains much brown ovoid chert, and some zones are crowded with rudistids and Gryphaeas. The formation contains many fossils, but identifiable specimens are not easy to obtain. These genera and species were collected:

Gryphaea mucronata Gabb
Protocardia multistriata
Pecten georgetownensis (?) Kniker
Pecten (*Neithea*) aff. *duplicosta*
Marcocallista (?) sp.
Toucasid sp.
Kingena wacoensis (Roemer)

The upper 175–200 feet of metamorphosed limestone strata exposed on the north and northwest slopes of Cienega Mountain is believed to represent the Georgetown limestone. The beds are highly fossiliferous, containing rudistids, chamids, gastropods, oysters, and dams, but no index fossils were collected. In the contact aureole around the larger of two syenite masses cutting the limestone, a marble quarry was opened several years ago. The quality of the stone is fairly good, but the dark color is not particularly attractive, and the project failed for the lack of a market.

There are several small, isolated patches of Cretaceous limestone low on the south slope of Cienega Mountain with fossils similar to those found in the strata assigned to the Georgetown on the opposite side of the mountain. These blocks were dragged up from below by the syenite mass upon which they now rest.

The Georgetown limestone in the Mt. Ord area lies disconformably (?) on the Edwards limestone and is conformably overlain by the Grayson marl. On the northern slopes of Cienega Mountain it rests on Edwards and/or intrusive syenite and is capped by Pruett tuff. Although the fossiliferous Kiamichi clay and marl, an easily recognized unit between the Edwards and Georgetown on the east and southeast flanks of the Marathon dome, cannot be distinguished here, careful paleontologic work might show the presence of equivalent limestone beds.

Grayson (*Del Rio*) *marl.*—Near the base of the prominent Mt. Ord escarpment in the northeast corner of the quadrangle, conformably on Georgetown limestone and disconformably below Buda limestone, is the Grayson marl—10–20 feet of soft, yellow greenish-gray, laminated to massive, fossiliferous, calcareous day and marl containing thin, rusty brown flags of sandy limestone crowded with the large agglutinated foraminifer *Haplostiche texana* (Conrad). Exposures along the steep debris-strewn slopes are not numerous but are frequent enough to indicate that the formation is continuous. Exposures are better on the more gentle slopes of the Del Norte Mountains across Chalk Valley to the southeast (in Monument Spring quadrangle)—a southeastward extension of the outcrop in the Mt. Ord area. The marl can be seen also in discontinuous outcrops northward from Mt. Ord to the northern extremity of the Del Nortes. Fossils found in the Grayson in the Mt. Ord area are:

Haplostiche texana (Conrad)
Gryphaea sp.
Exogyra arietina Roemer
Exogyra cartledgi Böse

Buda limestone.—Buda limestone crops out near the base of the escarpment around Mt. Ord and at the foot of Elephant Mountain; the best exposure in the northeast corner is on the north side of Mt. Ord. Near the base of the east-facing Mt. Ord escarpment float from the overlying Pruett tuff obscures the outcrop.

The Buda limestone has a distinctive lithology. Where fully exposed it nearly always shows three members: (1) a lower; gray, thick-bedded, fine-grained, brecciated limestone, (2) a middle; gray, nodular, fine-grained limestone and buff to gray, thin-bedded, fine-grained fossiliferous marl, and (3) an upper; light-gray to white, porcelaneous, thick-bedded, brecciated limestone. Its 60–70-foot thickness is uniform over a wide area, measuring 68 feet at Mt. Ord and 65 feet at Elephant Mountain. Fossils are abundant in the Buda, especially in the middle nodular and marly member. The fossils collected were:

Turritella budaensis Shattuck
Alectryona sp.
Gryphaea graysonana Stanton
Lunia wacoensis Roemer
Cardium (*Protocardia*) sp.
Pecten (*Neithea*) *texanus* Roemer
Pecten (*Neithea*) *whitneyi* Kniker
Pholodomya roemeri (?)
Stoliczkaia n. sp.
Hemiaster calvini Clark
Heteraster sp.
Budaiceras sp.

The wavy contact between the Buda and the underlying Grayson marl suggests a disconformity. At Elephant Mountain the Buda is overlain disconformably by the Boquillas limestone; in the Mt. Ord area it is capped by erosional remnants of the Boquillas and/or Pruett tuff.

Boquillas limestone.—A flaggy limestone facies of the Boquillas formation represents the Gulf series. There are several isolated outcrops of small areal extent in the southeastern and northeastern corners of the quadrangle. Better exposures with greater thicknesses occur along the west slopes of the Del Norte and Santiago mountains in Monument Spring and Santiago Peak quadrangles and to the south in Buck Hill and Agua Fria quadrangles.

The lithology—thin limestone flags and interbedded shale—is similar to that of the type Boquillas near Hot Springs in Big Bend National Park. The flaggy beds are light-gray to brown, fine-grained, fossiliferous limestones of varying purity in layers from 1 to 6 inches thick. Some strata are hard, nearly pure limestone; others are chalky and contain much fine sand and clay material. Banding caused by limonite staining is common. The flags tend to weather into small rectangular blocks. Partings of soft, gray to brown, laminated shale, sandy clay, and marl from a fraction of an inch to a foot or more in thickness separate the limestone beds. Boquillas limestone crops out discontinuously along the lower slopes of the escarpment around Mt. Ord. Because wash and gravity-moved materials from the overlying volcanic rocks cover most of the slope, good exposures are rare; and although these few outcrops appear to be only isolated erosional remnants, a thin layer of Boquillas could well be present all along the escarpment between the Buda limestone and the Pruett tuff. The formation has been traced from one small outcrop to another, along the base of the eastern edge of the Tertiary volcanic rocks to the northeast corner of the Alpine (15-min.) quadrangle, approximately 15 miles north of Mt. Ord. The broken and tilted attitude of the Boquillas beds—deformation not reflected in the underlying formations—strongly suggests that these small outcrops are discontinuous and were outliers on the Buda limestone at the beginning of the deposition of the overlying Pruett tuff. The deformation is of a type that could be produced by sliding or tumbling of large blocks down a slope or by slumping into a solution cavity. The thickest outcrop along the Mt. Ord escarpment, on the north side of Mt. Ord, is approximately 75 feet; other outcrops measured range from a few feet up to 50 feet in thickness.

A small mass of Boquillas limestone is exposed in the northern part of the Mt. Ord basin immediately southwest of Mt. Ord. Its structure is domical, with the beds dipping sharply (20°–70°) in all directions. Whether this outcrop represents a hill on the old pre-Tertiary erosional surface or the top of a small covered laccolith is not known; lack of metamorphism of the limestone or observable deformation of the overlying tuff suggests the former.

The Boquillas outcrop in the low area between Elephant Mountain and North Crossen Mesa is associated with an igneous intrusion. A boss on the syenite mass which supplied the thick sill capping Elephant Mountain arched the Boquillas and overlying Tertiary volcanic rocks. This small laccolithic structure was later breached by erosion, exposing tilted beds of Pruett tuff, Boquillas limestone, and small areas of the syenite core. The Boquillas is in direct contact with the syenite and has been slightly metamorphosed; the limestone is dark gray to black and the shale is purplish. The thickest section, about 53 feet, is exposed along a small creek in the eastern half of the main outcrop area.

Outcrops of Boquillas and Buda limestones cover a small area near the foot of Elephant Mountain in the southeast corner of the quadrangle, the northern margin of a larger area of outcrop in the northeast corner of Buck Hill quadrangle. Study of the Cretaceous beds in this area is difficult because debris from the overlying volcanic rocks covers the slope of Elephant Mountain. Goldich and Elms (1949, p. 1177–1178) measured a section of Buda and Boquillas south of the quadrangle boundary (beginning in a gully 3 miles northeast of Kokernot ranch house) which has 38 feet of gray, massive Buda limestone and 117 feet of Boquillas. Their Boquillas section includes 64 feet of lower flaggy beds and 53 feet of upper limestone beds. On the basis of Foraminifera, Goldich and Elms (1949, p. 1143) correlated the upper 53 feet of beds with the lower Austin. Only the lower flaggy section is known in the Cathedral Mountain quadrangle.

These fossils were collected from outcrops of Boquillas limestone on the north side of Elephant Mountain and in the Mt. Ord area:

Inoceramus dimidius White
Inoceramus inconstans Woods
Inoceramus inconstans striatus Mant.
Inoceramus fragilus Hall and Meek
Inoceramus labiatus Schlotheim
Coilopoceras (?)

Tertiary System

General.—Volcanic rocks of Tertiary age, aggregating more than 4600 feet, including basaltic, andesitic, trachyandesitic, trachytic, and rhyolitic lavas, and thick tuffs and tuffaceous rocks containing sandstone, conglomerate, and nonmarine limestone, overlie marine Cretaceous rocks; their outcrops occupy more than 90 per cent of the quadrangle. Also, fairly large areas of tabular and domical intrusive masses of alkalic syenite are exposed at several places. The volcanic rocks are divided into nine formations, which are from oldest to youngest: Pruett, tuff, Crossen trachyte, Sheep Canyon basalt, Potato Hill andesite, Cottonwood Spring basalt, Duff formation, Mitchell Mesa welded tuff, Tascotal formation, and Rawls basalt. The grouping and nomenclature follows, with minor modifications, the work by Goldich and Elms (1949, p. 1143–1163).

Little was known about these rocks in the Davis Mountains and adjacent areas to the south before the original work of Goldich and Elms (1949, p. 1143–1163) in Buck Hill, northern Jordan Gap, and southern Cathedral Mountain quadrangles. They applied the name Buck Hill volcanic series to the 3000–4000 feet of volcanic rocks resting unconformably on marine Cretaceous strata in the area between the Alpine intrusive igneous center on the north and the Terlingua center to the south. To a succession of five lavas alternating with five tuffs, some of which contain sandstone, breccia, conglomerate, and limestone, 1500–1700 feet thick, resting on Gulf rocks in the northeastern Davis Mountains (Barrilla Mountains), Eifler (1951, p. 342) gave the name McCutcheon volcanic series and divided it into three formations named, from oldest to youngest, the Huelster formation, Star Mountain rhyolite, and Seven Springs formation. There are considerable differences, both in thickness and lithology, between the Buck Hill and the McCutcheon series. These two successions represent conditions at opposite edges of one great volcanic field, and their relations will probably show clearly when the central Davis Mountains have been studied. The volcanic rocks which cover the Cathedral Mountain quadrangle are typical of the Buck Hill series; toward the north, in the Alpine (15-min.) quadrangle, the rocks begin to show affinity with the McCutcheon series.

Goldich and Seward (1948, p. 14) divided the Buck Hill series into six formations named, from oldest to youngest, Pruett formation, Cottonwood Spring basalt, Duff formation, Mitchell Mesa rhyolite, Tascotal formation, and Rawls basalt. The writer uses essentially the same divisions as employed by Goldich and Seward, except that the "intercalated" flows in their Pruett formation are treated as separate formations, and the name "Pruett" is restricted to the tuff, sandstone, conglomerate, and limestone below the Crossen trachyte. The thin weathered tuff members separating the flows are included with the underlying flow in each formation. The name for the Mitchell Mesa "rhyolite" is changed to Mitchell Mesa welded tuff.

Pruett tuff.—Goldich and Elms (1949, p. 1145) described the Pruett formation as "... principally volcanic tuff but includes conglomerate, tuffaceous sandstone and breccia, and tuffaceous fresh-water limestones. Interfingering with the tuff are flows of trachyte, basalt and andesite." To the "intercalated" flows they gave the names Crossen trachyte, Sheep Canyon basalt, and Potato Hill andesite. They believed that deposition of the tuff and related sediments was locally interrupted by invasions of lava from the north. This conclusion is a logical interpretation of relations south and southwest of the Cathedral Mountain quadrangle (where, for example, the Cottonwood Spring basalt rests on lower Pruett tuff in the Buck Hill quadrangle but is missing in Tascotal Mesa quadrangle). But to the north in the Cathedral Mountain and Alpine (15-min.) quadrangles the flows are continuous and very extensive, not local intercalations. The flow units are separated from one another by erosional unconformities; for example the Sheep Canyon basalt poured out on a hill-and valley topography developed on Crossen trachyte, with the valleys cut through the trachyte and into the underlying tuff. The layers of tuff separating the lavas show considerable weathering, and in places much of this "tuff" is a product of decomposition of the underlying lava. The Pruett tuff, as interpreted by the writer, represented a time of dominant tuff deposition ending with the beginning of Crossen trachyte flows; Crossen time ended after a long period of erosion with the outpouring of the first of the Sheep Canyon flows; and so on. For these reasons, the Crossen trachyte, Sheep Canyon basalt, and Potato Hill andesite are treated as formations, and the name Pruett tuff is restricted.

The Pruett tuff is exposed in the slope of the generally east-facing escarpment which extends from the central part of the southern boundary, along the east margin of Crossen Mesa, in a northeasterly direction to Mt. Ord, in the northeast corner of the mapped area. It has been traced northward along the scarp forming the eastern boundary of the Tertiary volcanic rocks to the northeast corner of the Alpine (15-min.) quadrangle. The formation crops out in the walls and floor of the Mt. Ord basin and in slopes of Elephant Mountain, especially along the east side. The thickest section and one of the best exposures in the area is immediately north of the marble quarry, on the north side of the Cienega Mountain laccolith; smaller areas outcrop around the base of Cienega Mountain on the northwest, west, and south sides. About 300 feet of Pruett tuff is exposed immediately east of the McIntyre Peak intrusion.

This nonresistant basal formation capped by more resistant lavas crops out in fairly steep slopes with more or less concave profiles littered with talus or covered with colluvium. No complete section can be seen at any single locality. The base and upper part are exposed only in a few places.

The Pruett tuff averages 597 feet thick between the Pruett ranch in Buck Hill quadrangle and the northeast corner of the Alpine (15-min.) quadrangle (a north-south distance of about 35 miles); the minimum thickness, at a place in the east-central part of the Alpine (15-min.) quadrangle is 260 feet; the maximum thickness, in the tilted section north of Cienega Mountain, is 798 feet (measured section 1, Pl. 1).

The Pruett tuff consists chiefly of well-indurated, thick-bedded, calcareous, highly altered volcanic glass and fine- to medium-grained tuffaceous sedimentary rocks in various shades of gray, red, green, and speckled combinations, light gray predominating. Some exposures show well-developed stratification. At places beds of incoherent and friable material appear to be nearly pure volcanic ash. Locally, the fine-grained material is silicified. Individual beds are not distinctive and persistent enough to allow correlation between outcrops. The typical tuffaceous beds are composed of a great deal of clay containing mineral and glass particles 0.01 mm–0.07 mm in diameter. Approximately 40 per cent of the average tuff sample has grain size less than 0.015 mm. G. C. Hardin, Jr. (unpublished manuscript, 1942) identified quartz, orthoclase, plagioclase, olivine, biotite, chlorite, sphene, normal zircon, epidote, magnetite, hematite, limonite, apatite, pyroxene, and sericite. Magnetite, usually partly altered to hematite and limonite, is the principal constituent of the heavy-mineral fraction. Quartz, orthoclase, and biotite are the most obvious minerals in thin sections.

Also included in the formation are conglomeratic tuffaceous sandstone, breccia, and considerable limestone, but these types are more distinctive in the Buck Hill quadrangle.

Most beds in the Pruett are calcareous ranging from slightly calcareous tuff and tuffaceous sandstone to tuffaceous limestone and pure calcitic limestone. Bedding in the limestone ranges from thick to massive. The limestone is dominantly light gray but in some places is darker gray and brown. Some limestone is present wherever a nearly complete section is observable; it occurs at intervals in beds 3–10 feet thick. There are thick accumulations at a few places, particularly in the spur between Sheep Creek and Calamity Creek northeast of Crossen Mesa, in the big re-entrant of the escarpment along the west side of Chalk Valley, and in the Mt. Ord basin.

In the spur between Sheep and Calamity creeks is a sequence of interbedded limestone and calcareous tuff about 300 feet thick; of which the upper 200 feet is light-gray to brown, fine-grained, thick-bedded, fossiliferous, nearly pure calcitic limestone. Beds a few feet thick near the contact with the overlying Sheep Canyon basalt have been mostly replaced by silica. In the big re-entrant of the Mt. Ord scarp, along the west side of Chalk Valley, 55 feet of calcareous tuff and limestone (two 20-foot layers of limestone separated by 15 feet of calcareous tuff) caps the Pruett tuff and is overlain by Sheep Canyon basalt. It is an interesting fact that in these two areas the Crossen trachyte is absent because of pre-Sheep Canyon erosion and the Sheep Canyon **basalt** rests directly on limestone and tuff which appears to be continuous with the Pruett tuff.

Although the limestone is mapped as Pruett, part or all of it may be post-Crossen. The trachyte was completely breached in these two areas, and erosion may have cut deeply into the underlying Pruett tuff. Such valleys could have contained lakes in which the limestone beds were deposited before the Sheep Canyon basalt covered the surface. Limestone with the same color, texture, and fossil content in beds 3–10 feet thick is common in the tuffaceous layers between flows of the Sheep Canyon basalt. On the other hand, the widespread limestone in unquestioned Pruett tuff also is similar to that in the abnormally thick sections and to the limestone in the Sheep Canyon basalt. Gastropods in the limestone are of no value for correlation. Similarity of lithologic characteristics and fossil content does not rule out a considerable age difference; it does seem to indicate that similar environments were recurrent over a long period of time.

Fairly good exposures in the Mt. Ord basin show several interbeds of limestone in a tuff section capped by Crossen trachyte—wholly Pruett tuff. But there the limestone occurs in beds 3–8 feet thick separated by much thicker tuff layers; the limestone beds appear to be widespread with no local thickening. Chert and fine-grained quartz in irregular-shaped masses and thin stringers are important constituents of the limestone in this area. A typical sample treated with hydrochloric acid yielded a siliceous residue equal to 38 per cent of the original weight. But limestone containing appreciable siliceous material is common in the Pruett tuff.

In the Buck Hill quadrangle, conglomerate composed of well-rounded pebbles of limestone, marble, quartzite, silicified wood, and chert is widespread at the base of the Pruett, but at the few places where the base is exposed in the Cathedral Mountain quadrangle there is little or no conglomerate. Conglomeratic layers do occur at different horizons in some sections; for example, an outcrop on the north side of Cienega Mountain contains two conglomerates; one 278 feet above the base is 48 feet thick, and the other 420 feet above the base is 12 feet thick. In the escarpment on the west side of Chalk Valley, in the upper part of the formation, 50 feet of conglomeratic sandstone containing vertebrate fossils (measured section 13, Pl. 1) is probably equivalent to the breccia-conglomerate facies that occurs about 60 feet below the top of the Pruett tuff in Buck Hill quadrangle. No conglomerate occurs, however, in an exposure about a mile north of the vertebrate fossil locality, nor in the Mt. Ord basin. The conglomerate beds are lenticular and do not persist for any great distance. Beds observed are composed of well-rounded, poorly sorted, gray, pink, and brown gravel, ranging from granule to cobble in size (mostly pebble), of fine-grained igneous rock, hard silicified tuff, and limestone held together by a medium- to coarse-grained, calcareous, tuffaceous sandstone matrix.

Much fine-grained, thick-bedded to massive tuff is conglomeratic in that it contains harder, more indurated nodules or pellets with the same texture and composition as the matrix. The tuff "gravel" ranges in diameter from a fraction of an inch to about 2 inches, and the shape is somewhat irregular but mostly slightly flattened spherical or elliptical. In some beds these pellets are scattered and constitute a minor part of the rock, but in others they make up a high percentage of the total volume. Because they are harder and more resistant than the matrix, they weather out and litter the slopes. Clifflike exposures show numerous pits originally occupied by the nodules. These nodules may represent mud balls or pellets formed in the air from fine ash emitted as part of moisture-laden, smokelike clouds and deposited as such in a matrix of softer volcanic mud. "Mud pellets" or "volcanic hailstones" have been observed during several volcanic eruptions and are recorded from Triassic and Miocene tuffs and recent ash deposits (Shrock, 1948, p. 331-333).

Tuffaceous, calcareous sandstone is an important constituent of the beds in all parts of the section. It is gray to greenish gray or brown, thin- to thick-bedded, medium- to coarse-grained, and is poorly to well cemented with calcite.

Algal structures, charaphytes, and fossil gastropods and ostracods are abundant. Concentric algal structures make up a large part of the rock. Similar algal limestone occurs in the Huelster formation in the Barrilla Mountains (Eifler, 1951, p. 344).

Several tuff beds around Elephant Mountain contain many internal casts of an unidentified medium-sized (½–1½ inches in diameter), low-coiled land snail; an unidentified, small (1/4–3/4 inches long), high-spired form is common in association with vertebrate remains in a conglomerate near the top of the Pruett tuff, in the east-facing escarpment along the southeast margin of North Crossen Mesa, 2.28 miles along a bearing N. 26° W. from Nevill's Chalk Valley house at the northeast end of Elephant Mountain. Titanothere remains including fragmentary vertebrae, skull, and jaw fragments (without teeth), and pieces of miscellaneous skeletal parts were taken from this site. The writer also collected vertebrate material from the upper breccia in the Pruett tuff on a small hill west of Cottonwood tank on the 02 Ranch, in northern Buck Hill quadrangle. A well-preserved lower jaw (complete with teeth) of a titanothere, a lower jaw without teeth of a small rhinoceros, and miscellaneous bone and tooth fragments were obtained from the vicinity of Cottonwood tank.

The Pruett tuff rests with angular unconformity on marine Cretaceous rocks, probably on the Boquillas limestone over most of the area. Around Mt. Ord, where the Boquillas was removed by erosion prior to deposition of the tuff, it rests on Buda limestone. Northward from Mt. Ord, to the northeast corner of the Alpine (15-min.) quadrangle, the Pruett overlies Boquillas limestone. On the north and northwest sides of the Cienega Mountain laccolith, it rests on Georgetown limestone; on the south and southwest sides it is in contact with intrusive syenite. It is not known whether the relations seen at the surface represent the true stratigraphic relations in the subsurface in the Cienega Mountain area. Certainly, the discontinuous outcrops on the south and southwest sides are blocks which were torn loose and elevated by intrusion, and possibly the Georgetown limestone was pushed past Gulf beds to a position in contact with the Pruett on the north and northwest limbs during development of the laccolithic structure.

In the Cathedral Mountain quadrangle and the Alpine (15-min.) quadrangle the Pruett tuff is overlain by the Crossen trachyte, except in the Sheep Canyon area and in the vicinity of the big re-entrant on the Mt. Ord escarpment where the Crossen was eroded away prior to extrusion of the Sheep Canyon basalt, and over the eastern half of Elephant Mountain where it is capped by a syenite sill.

Crossen trachyte.—Goldich and Elms (1949, p. 1151) gave the name Crossen trachyte member to a massive porphyritic trachyte flow capping Crossen Mesa in northern Buck Hill and southern Cathedral Mountain quadrangles and considered it as the lowermost lava in their Pruett formation. This flow has been traced to the northeast corner of the Alpine (15-min.) quadrangle. It forms broad outcrops on Crossen Mesa, North Crossen Mesa, the summit and slopes of Mt. Ord, and over a wide area across the eastern half of the Alpine (15-min.) quadrangle (Fig. 2). Local outcrops occur around Cienega Mountain and McIntyre Peak, where it was arched by intrusive masses and later exposed by erosion.

The unit extends more than 400 square miles, and for this and other reasons the Crossen trachyte should be considered a separate formation.

The description of the Crossen trachyte in Buck Hill quadrangle applies to most of the outcrops of the formation in the Cathedral Mountain quadrangle. It is one of the most distinctive units in the volcanic series and is easily recognized in the field. In the Crossen Mesa area the average thickness is about 150 feet, but it thickens northward, and the average for the Cathedral Mountain and the Alpine (15-min.) quadrangles is approximately 200 feet. The maximum known thickness is at Mt. Ord where 265 feet caps the summit area.

Locally, no trachyte is present, and the Sheep Canyon basalt rests directly on the Pruett tuff. The absence of the trachyte in Elephant Mountain is probably due to pre-Sheep Canyon stream erosion. Inliers, ancient erosional remnants, are exposed in the Sheep Canyon area and in a valley south of Clark ranch headquarters, and an ancient hill-and-valley topography has been exhumed in many places.

Although there are local vesicular zones at different horizons, it appears to be one massive flow. The rock is hard, gives a metallic ring when struck with a hammer, and breaks with an even to subconchoidal fracture. Medium-sized, squarish, glassy phenocrysts of anorthoclase and sanidine are abundant in a fine-grained, reddish-brown groundmass. The weathered rock is nearly everywhere rusty brown; locally it is greenish or various shades of yellow. A distinctive feature of weathered material is the pitted surface which results from weathering out of the feldspar phenocrysts. Local highly weathered areas range from rotten, greenish-yellow, vesicular material to a fine-grained, grayish-yellow, tufflike decomposition product. Perhaps these highly altered materials are remnants of an ancient mantle developed on the trachyte surface.

The flow has well-developed vertical jointing and tends to form nearly vertical cliffs at the edges of mesas and along the escarpment that trends across the east side of the quadrangle. Marginal fragmentation provides abundant scree at the base of the cliffs and over the slope of the underlying Pruett tuff; large talus deposits are especially prominent on the slopes of Mt. Ord.

Vesicular zones in the upper part contain amygdules of chalcedony, some of which are banded with delicate pink, red, and bluish tints and are much prized by agate collectors. Locally, the vesicles are strongly elongated and aligned in a northwestern direction.

The fine-grained, trachytic groundmass consists chiefly of microlites of alkalic feldspar and some altered ferromagnesian material, and finely disseminated hematite gives it a reddish tinge. The squarish feldspar phenocrysts have irregular margins and are principally anorthoclase, with some sanidine. Altered dark-green grains are probably aegerine-augite. Introduced chalcedony is abundant as veinlets and also lines the walls of small cavities in some specimens. All specimens studied from the Cathedral Mountain quadrangle, except two, appear to contain more than 90 per cent alkalic feldspar and little or no primary quartz. Rock from the outcrop on the east side of the McIntyre Peak intrusion contains about 15 per cent primary quartz and must be classed as rhyolite; an inlier south of Clark ranch on State highway No. 118 also contains an appreciable amount of quartz. Quartz is abundant (5–10 per cent) in samples from several outcrops scattered over the eastern half of the Alpine (15-min.) quadrangle. A chemical analysis of a specimen from Crossen Mesa (Goldich and Elms, 1949, p. 1152) shows a silica content of 71.17 per cent, unusually high for trachyte. The rhyolitic composition of the flow in the McIntyre Peak area is puzzling. There is no doubt that the flow occupies the position of the Crossen. Moreover, the rock looks like typical Crossen trachyte. At Mt. Ord, about 8 miles due east, the rock contains no discernible primary quartz. Unfortunately the area between the outcrops at Mt. Ord and McIntyre Peak is covered by younger flows. In the continuous outcrop from the Mt. Ord area northward across the eastern portion of the Alpine (15-min.) quadrangle no new flow or any suggestion of a facies change is apparent. Yet the flow is rhyolitic in most places north of Mt. Ord.

Sheep Canyon basalt.—The Sheep Canyon basalt overlying the Crossen trachyte is a succession of basaltic lavas separated by thin layers of tuff and limestone (Goldich and Elms, 1949, p. 1153). This formation has wide distribution in the Cathedral Mountain and Alpine (15-min.) quadrangles and, before erosion stripped it off, probably covered much of the country to the south and east. It thins and feathers out southward in northern Buck Hill quadrangle. The thickness gradually increases northward and the greatest known thickness is in an area on the Lane and Decie ranches about 6 miles south of Alpine. The lava was poured out on a very irregular surface, and the number of flows, thickness of individual flows, and the total thickness of the formation vary considerably. A 251-foot section (measured section 4, Pl. 1) contains five flows and four thin tuff and limestone interbeds. (A lava between tuff or limestone partings is considered as a single flow.) If vesicular "tops" were used to distinguish separate flows, it would be possible to recognize several in a given unit, but this method is unreliable. Sections measured at different places over the quadrangle show variation in the number of flows and in total thickness (including tuff and limestone beds) as follows: near the southern boundary on Crossen Mesa, 3 flows, 163 feet; in the Goat Creek and Walnut Draw, 1 flow, 62 feet; North Crossen Mesa, 3 flows, average of 4 sections—190 feet; on Bird ranch west of Ash Creek, 1 flow, 41 feet; on northwest side of Cienega Mountain, 4 flows, 316 feet; in Ash Creek area west of Mt. Ord, 4 flows, 454 feet; in spur between Sheep and Calamity creeks, 5 flows, 251 feet; in Sheep Canyon area, 4 flows, 234 feet.

In Elephant Mountain, complex faulting and lack of good exposures make it difficult to determine the true thickness of the Sheep Canyon formation. Although parts of the unusually thick sections exposed there have been duplicated by normal faults, the actual section appears to be thicker than in the near-by Sheep Canyon and Crossen Mesa areas. A section measured up the west slope, due east of the mouth of Sheep Creek, contains four flows and is 372 feet thick. As the area now occupied by Elephant Mountain was a lowland at the beginning of Sheep Canyon eruptions, the Crossen trachyte having been eroded from the entire area, it is not surprising to find there a thick section of the basaltic lavas of the Sheep Canyon formation.

The greatest accumulation of Sheep Canyon basalt in either the Cathedral Mountain quadrangle or the Alpine (15-min.) quadrangle seems to have been in a basin extending from a point on the west side of Mt. Ord northward to the vicinity of the town of Alpine. West of Mt. Ord, on the west side of Ash Creek, the formation is 454 feet thick. On the Lane and Decie ranches, about 6 miles south of Alpine, a section of undifferentiated Sheep Canyon, Potato Hill, and Cottonwood Spring flows totals 1178 feet, more than 400 feet of which is Sheep Canyon; in a water well drilled on the northern outskirts of Alpine the Sheep Canyon basalt measured 324 feet.

Except for local occurrences of large hypersthene phenocrysts in the first and third flows, all the basalt flows look alike and cannot be distinguished lithologically. All are porphyritic with an even-textured, fine- to medium-grained groundmass. Large, yellowish-orange, greenish, and dear prismatic phenocrysts of labradorite are common but have an erratic distribution. They range in length from a fraction of an inch to more than 3 inches, with sizes between ½ and 1½ inches predominating.

Many of the vesicular tops are thick and contain much quartz, several varieties of chalcedony, and calcite; high-grade, banded, and moss agate occur in these zones. Also, the vesicles contain much soft greenish material (chlorite?), which gives the zone a distinctive green color. Flow breccias, although not so conspicuous as those in the overlying Potato Hill and Cottonwood Spring flows, are well developed locally.

Slope, drainage, and exposure have greatly influenced weathering of the flows. Spheroidal weathering is especially well developed in gullies, on benches, and on gentle slopes, while platy sheetlike jointing develops on steep, well-drained slopes. Scattered over the surface in areas of spheroidal weathering are many spherical cobbles which represent cores of exfoliated masses. The cobbles weather a dull reddish brown, which is one of the most distinctive features of Sheep Canyon basalt. The color of the fresh break of these cores, a distinctive jet to dark greenish black, is characteristic of all fine- to medium-grained Sheep Canyon flows.

The dominantly feldspathic groundmass has a well-developed diabasic texture. Twinned plagioclase laths (labradorite An_{55}) range from 0.1 mm to about 0.5 mm in length. Labradorite phenocrysts range from a few millimeters to several centimeters in length. Some of the larger plagioclase phenocrysts are zoned, with cores as calcic as An_{60} (Goldich and Elms, 1949, p. 1154). Alkalic feldspar is abundant around the edges of the plagioclase laths and as interstitial filling. Plagioclase and alkalic feldspars make up approximately 70 per cent of the rock. Slightly pleochroic, light purple augite (probably titanaugite) constitutes from 15 to 20 per cent of the rock and occurs in fairly large crystals enclosing feldspar and other minerals. Olivine ($Fo_{70}Fo_{30}$, according to Hardin, 1942) in the form of small subhedral crystals is an important constituent in some of the slides studied, but in most specimens all original olivine is completely altered to antigorite and other decomposition products. Other minerals present are: magnetite, 10–15 per cent; abundant apatite in tiny prismatic crystals; chlorite and antigorite, 5 per cent; some calcite replacing the edges of feldspar laths and in radial clusters; and varying amounts of analcime, zeolites, and clay minerals. Alkalic feldspar is possibly sufficiently abundant to justify calling the rock trachybasalt.

At places between the Crossen trachyte and the first Sheep Canyon flow, everywhere between each flow in the Sheep Canyon succession, and separating the uppermost flow from the overlying Potato Hill andesite are thin layers of altered tufflike basaltic materials or tuff breccia, or limestone, or combinations of these in layers that average about 4.5 feet in thickness, ranging from less than 1 foot to 15 feet. The thickness of the weathered material capping the uppermost flow ranges up to 60 feet, averaging 15 feet. Beds of light-gray to dark-brown, cherty, fossiliferous limestone are common between flows in the southeastern part of the quadrangle. On the west slope of Elephant Mountain, beds of limestone 3–6 feet thick occur between each flow, and a measured section in the Sheep Canyon area (measured section 4, Pl. I) contains one 3-foot bed between the third and fourth flows. The limestone appears to be identical, both in lithology and fossil content, with that found in the Pruett tuff. Where limestone is lacking, as in outcrops in the western and northwestern parts of the mapped area, the thin intervening beds are composed of tuff or tuff breccia, or a zone of tufflike decomposed basalt.

Silicified, gray tuff and tuff breccia, which are fairly common, show phenocrysts and angular fragments of sanidine and quartz in a glassy matrix with more or less well-developed flow structure; several other minerals occur in lesser amounts including magnetite, hematite, limonite, aegerine-augite, riebeckite, sphene, zircon, chalcedony, and calcite. These probably represent rhyolitic tuff indurated by the overlying flow. In places where the interbedded tuff is not so well indurated and silicified it is rusty brown and much altered from ancient weathering but appears to have been originally rhyolitic tuff. Thin sections of tufflike material resting on the uppermost flow show it to be highly decomposed basalt—probably a product of residual weathering. It is reddish brown and consists of small fragments of basalt containing microlites of plagioclase feldspar in a fine-grained matrix of clay minerals and zeolites.

In most places the Sheep Canyon basalt rests on the eroded surface of Crossen trachyte; but locally it rests on Pruett tuff, in areas from which the trachyte was removed by pre-Sheep Canyon erosion. The unit is overlain by the Potato Hill andesite.

Potato Hill andesite.—Overlying the Sheep Canyon basalt is an andesitic flow and flow breccia designated Potato Hill andesite (Goldich and Elms, 1949, p. 1155). The dark reddish-brown color of the weathered rock together with abundant stubby, glassy plagioclase phenocrysts make this formation easy to recognize throughout the southern half of the quadrangle. It was used as a key bed in mapping the southern area. But there is a gradual facies change northward, and in the northern part of the quadrangle it is a greenish-gray, fine-grained nonporphyritic rock.

Because the lava spread over a highly weathered and somewhat irregular surface of Sheep Canyon basalt and was in turn subjected to a long period of weathering, and because of primary-flow phenomena which may have influenced differential accumulation, the thickness ranges from 35 to 190 feet; the average for 26 measured sections is 79 feet. The minimum thickness (35 feet) is found in the northwest side of North Crossen Mesa; the maximum (190 feet) is in a spur along the west side of Ash Creek between the Clark ranch house and the foreman's house on the Bird ranch. Another area of local thickening is in the upper Sheep Canyon region where the formation is about 100 feet thick. In most outcrops the thickness is 40–90 feet.

Conspicuous, stubby, orange and pinkish, glassy phenocrysts of andesine are abundant in the rock across the southern third of the area but gradually decrease in number northward, finally disappearing in the northern part. The change from highly porphyritic to nonporphyritic can be observed along nearly continuous outcrops. The texture of the groundmass also changes gradually from fine- to medium-grained in the south to very fine-grained in the north. In the field the nonporphyritic fades differs markedly from the porphyritic rock. The very fine-grained nonporphyritic lava weathers greenish gray and develops thin sheet jointing which supplies abundant rectangular chips to the slopes, while the porphyritic facies with its massive flow breccia and thick vesicular zone weathers reddish brown and furnishes irregular blocks and crumbly vesicular material to slopes and benches developed on the outcrops. The vesicular zone contains appreciable amounts of chalcedony (several varieties), calcite, and greenish chloride (?) material at many places, where it weathers to a greenish color.

Because of the marked change in facies and general appearance of the flow, the stratigraphically equivalent unit in the northern half of the area was not mapped as Potato Hill andesite until study of thin sections of the rocks and comparisons of silica content determined by measuring the index of refraction of fused samples, a technique applied by C. C. Rix (1951, M.A. Thesis, Univ. Texas), seemed to justify such mapping.

Nine representative samples of Potato Hill andesite were taken at well-spaced intervals in a north-south direction across the area; the index of six was 1.555, and of the other three 1.535, 1.545, and 1.565, respectively. Four of the six samples with an index of 1.555 came from the northern nonporphyritic facies and two from the southern porphyritic facies. The sample with an index of 1.535, the northernmost sample used, came from an exposure on the west side of State Highway No. 118 west of Mt. Ord. The sample with the index of 1.565 came from a highly porphyritic zone in an outcrop on Crossen Mesa. According to the index curve worked out by Rix, the silica content for these samples ranges from 51.3 per cent to 64.6 per cent—all within the limits for andesite. The average, 57.4, is very close to the average (57.2) for the diorite-andesite family. The fine-grained nonporphyritic facies has a slightly higher silica content than the porphyritic facies, but this is not unusual. A chemical analysis of a sample of Potato Hill andesite from northern Buck Hill quadrangle shows a silica content of 61.46 per cent (Goldich and Elms, 1949, p. 1156).

The textures range from finely granular to trachytic and glassy. Alteration products, particularly hematite, hinder resolution of the groundmass, but in granular and trachytic specimens small lathlike crystals of andesine are abundant, and some alkalic feldspar is present in the interstices. Feldspar makes up to 70–85 per cent of the rock. Magnetite and its alteration minerals constitute 5–20 per cent. Other minerals occurring in lesser amounts are olivine, iddingsite, antigorite, biotite, chlorite, zeolites, and clay minerals. One specimen showed basaltic hornblende (about 5 per cent of rock) and one large clear phenocryst of a clinopyroxene with a large extinction angle. Porphyritic facies specimens contain numerous stubby plagioclase phenocrysts which range between 1 mm and 1 cm or more in length. Many of the phenocrysts are rounded and corroded, and some are zoned, ranging from An_{55} in the inner parts to An_{45} in the outer zones (Goldich and Elms, 1949, p. 1156).

A thin section of a red, baked, tufflike material capping the Potato Hill flow in the northern part of the area shows weathered igneous rock fragments up to 0.5 mm in length containing plagioclase microlites, grains and fragments of plagioclase and alkalic feldspar, magnetite, limonite, and chlorite (?) embedded in a matrix of clay minerals and zeolites. This rock is probably a residual decomposition product developed by weathering of the andesite before it was covered by younger flows. The upper surface of the lava shows effects of deep weathering and is overlain in many places by several feet of reddish "residual soil."

Cottonwood Spring basalt.—To a succession of lava flows, ranging from trachyandesite to olivine basalt, resting on Pruett tuff and overlain by the Duff formation in a downfaulted area in northeastern Buck Hill quadrangle, Goldich and Elms (1949, p. 1156) gave the name Cottonwood Spring basalt. Traced northward into the Cathedral Mountain quadrangle, these flows occupy a position between Potato Hill andesite and the Duff formation, a relationship which is maintained across the south-north length of the Alpine (15-min.) quadrangle. Stratigraphic relationships in Buck Hill, Cathedral Mountain, and Alpine (15-min.) quadrangles show that the Cottonwood Spring lavas came from the north and northwest and spread southward over a broad area from which Potato Hill andesite, Sheep Canyon basalts, and Crossen trachyte had been eroded. It may have reached farther south than any of the older flows.

The pre-Duff thickness of the Cottonwood Spring basalt can be determined only in the cuesta infaces on the northwest and west sides of Cienega Mountain—the only places where both the top and bottom of the unit are exposed. Elsewhere, the flows cap hills and highly dissected areas from which the Duff formation has been eroded. The Cottonwood Spring basalt is 286 feet thick in the only complete section measured (northwest limb of Cienega Mountain laccolith). Incomplete sections (erosional remnants) range from a few feet to 332 feet; the maximum occurs east of Goat Creek picnic grounds (may be duplicated by faulting). The average for 24 measured sections, representative of all outcropping areas, is about 150 feet. Between 500 and 700 feet of a 1178-foot section of basaltic lavas exposed on the Lane and Decie ranches, about 6 miles south of Alpine, belong to the Cottonwood Spring basalt. A water well in the City of Alpine penetrated 237 feet of Cottonwood Spring basalt. According to Goldich and Elms (1949, p. 1157) the maximum in northern Buck Hill quadrangle is 325 feet. DeFord (*in* Goldich and Seward, 1948, p. 37) gave a thickness of 220 feet for Cottonwood Spring basalt encountered in Argo Oil Corporation's Mitchell Bros—State No. 1 (now Gulf Oil Corporation's Mitchell Bros.—State No. 1) located on the southern edge of Whirlwind Mesa in the southwest quarter of the Alpine (30-min.) quadrangle, about 4 miles west of Walnut Draw.

Lack of well-exposed complete sections, the highly weathered condition of the outcrops, the variable number of flows, and the absence of key "beds" make the unit difficult to deal with in the field. It is not possible to correlate definitely any given flow over a sizable area. There may appear to be three flows at one place, while relatively near by there may be six or eight flows in a section of about the same thickness. Vesicular and amygdaloidal zones are numerous, and using these to determine the number of flows would give 15–20 in some sections, but many of these probably formed as thin lobes or tongues of advancing lava fronts and in turn were capped by several similar fronts before being covered by the main mass of the flow. As well as could be determined, there are four major flows of about equal thickness, but three are seen in most exposures, and many show only two.

In the northern Buck Hill quadrangle and the Cathedral Mountain quadrangle a thin tuff bed is near the middle of the formation, but this tuff cannot be identified with certainty in the northern half of the area. Locally, there are thin layers of tuff and highly weathered basaltic material between flows, but in most outcrops there are no separating tuff beds. Tuff is present between the Potato Hill andesite and the lowermost Cottonwood Spring flow at many places; elsewhere a flow breccia incorporating weathered blocks and cobbles of andesite rests directly on the Potato Hill.

The basalt is dark and fine- to medium-grained in both dense and vesicular phases. Except for rare small glassy plagioclase phenocyrsts in small local areas, the flows are nonporphyritic. The many vesicular and amygdaloidal zones contain considerable quartz, chalcedony, and calcite. Much highly prized moss and banded agate comes from vesicular zones and flow breccias in the Cottonwood Spring lavas. Massive coarse flow breccias at different horizons are very conspicuous, and ropy lava is common.

As in the Sheep Canyon lavas, topography and drainage largely control weathering. Well-developed spheroidal weathering occurs in gullies and sheltered areas; platy splitting develops on summits, steeper slopes, and cliffs. The rocks weather dark brown to light greenish gray.

One of the most characteristic features of Cottonwood Spring flows is the speckled schistose appearance of certain units owing to the subparallel arrangement of abundant shiny tabular crystals of plagioclase feldspar. The flaky crystals, 0.5–2.0 mm in diameter and 0.1 mm or less in thickness, have their flat surfaces nearly parallel to the direction of flow. Viewed in cross section, the thin edges present a distinct pilotaxitic texture; they appear as needlelike microlites very close together and nearly parallel.

The rocks range from soda-rich olivine basalt to trachyandesite, with some approaching trachyte. Two textures are found—diabasic for the basalts and bostonitic or trachytoid (irregular laths of feldspar arranged in a divergent subparallel manner) for the more silicic rocks. The finer-grained trachyandesites and "trachytes" possess a trachytoid texture which might be called pilotaxitic. Whether bostonitic or pilotaxitic, the subparallel feldspar laths and/or microlites show well-developed flow structure. Because the rock is so highly weathered, fresh samples are unobtainable; the original ferromagnesian minerals are much altered in most of the thin sections. Twinning is not well developed in most of the plagioclase, and much of the feldspar is characterized by wavy extinction. Orthoclase mantles the plagioclase laths, and alkalic feldspar occurs interstitially even in the basalts. Alkalic feldspar appears to exceed 50 per cent of the feldspar content in some of the more silicic types. Except for the feldspars, all the flows have essentially the same mineral composition. Olivine was originally abundant but is now largely altered to antigorite, iddingsite, and acicular serpentinous minerals which penetrate fractures in the feldspar. Augite, light purple and light green, constitutes 5–10 per cent, and magnetite 10–15 per cent of the rock. Needlelike crystals of apatite are exceedingly abundant in the diabasic rocks. Biotite is rare. Chlorite, calcite, chalcedony, analcime, and zeolites are secondary minerals present in varying amounts. Small patches of chalcedony replace feldspar in some of the rocks with trachytoid and pilotaxitic textures. The basalts contain 75–80 per cent feldspar, about three-fourths of which is labradorite and one-fourth alkalic feldspar. The proportion of alkalic to calcic feldspar in the other rocks appears to range from slightly more than 1:1 to about 3:5.

None of these soda-rich rocks are normal types. Following the usage of Lonsdale (1940), Goldich and Elms (1949, p. 1159) classified analyzed samples of the basal flow of the Cottonwood Spring formation in northern Buck Hill quadrangle as analcime trachybasalt.

Duff formation,—Resting on the weathered and eroded surface of the Cottonwood Spring basalt in northwestern Buck Hill, most of Jordan Gap, and Cathedral Mountain quadrangles, and on Pruett tuff in northeastern Tascotal Mesa quadrangle is a thick section of rhyolitic tuff containing lenticular beds of sandstone, breccia and conglomerate, and intercalated lava flows. In the southern half of the Cathedral Mountain quadrangle, and in quadrangles to the south and southwest, the formation is predominately thick-bedded, well-indurated, fine-grained rhyolitic tuff with subordinate tuff breccia, tuffaceous sandstone, sandstone, and conglomerate. The tuff is noncalcareous, except in Tascotal Mesa quadrangle where limestone is interbedded (Erickson, 1953, p. 1362). Two or more thin flows of trachybasalt and/or trachyandesite outcrop in southern Cathedral Mountain and Tascotal Mesa quadrangles; flows including trachyte, rhyolite, and basaltic types constitute a major part of the formation in the northern half of the Alpine (30-min.) quadrangle. The formation was named by Goldich and Elms (1949, p. 1159) for Duff Springs in northwestern Buck Hill quadrangle.

Outcrops of the Duff are extensive across the western part of the Cathedral Mountain quadrangle and are especially conspicuous in steep slopes of the east-facing Mitchell Mesa escarpment, Goat Mountain, Cathedral Mountain, and a line of narrow buttes extending northward from Cathedral Mountain. The entire section is exposed on the southeast side of Goat Mountain (measured section 10, Pl. 1) and in the east slope of Cathedral Mountain. The upper part of the formation crops out along major arroyos and numerous fault-line scarps on Mitchell Mesa; the lower beds cap the tilted volcanic sequence on the northwest side of Cienega Mountain laccolith. It is exposed over a wide belt extending northward from the Cienega Mountain syenite mass around Cathedral Mountain and northeastward along either side of Calamity Creek into the Alpine (15-min.) quadrangle. Alluvium covers the formation in the northwestern part of the area mapped. Acidic lavas (Decie member, Tdd on geologic map, Pl. 1) first appear as thin tongues near Haley Mountain and McIntyre Peak and increase in thickness very rapidly toward the north.

Thicknesses of the Duff formation are: 764 feet at Needle Peak in Tascotal Mesa quadrangle (Erickson, 1953, p. 1363); 1015 feet near Duff Springs in Buck Hill quadrangle (Goldich and Elms, 1949, p. 1160); 1500 feet in Argo Oil Corporation's Mitchell Bros.—State No. 1 in the southwest quarter of Alpine (30-min.) quadrangle (DeFord, *in* Goldich and Seward, 1948, p. 37); 1399 feet on southeast side of Goat Mountain; and more than 1500 feet west of McIntyre Peak. The maximum thickness will probably be found to the northwest, in the Paisano Peak quadrangle.

The tuff is chiefly fine-grained rhyolitic glass in various stages of alteration and contains scattered grains of feldspar and quartz and flakes of biotite. Most of the tuff is thick-bedded and well stratified, but some is massive; thinly laminated zones are present, and some is cross-bedded. The tuff is largely light gray—which appears glaring white in the brilliant west Texas sunlight; other colors include buff, brown, pink, and red. Small white chalky fragments, possibly kaolinized feldspar grains, in the fine-grained light gray matrix gives much of the tuff a speckled appearance. Many weathered slopes are strewn with small rounded tuff pellets and pebbles. Rounded nodules that make up an important part of some tuff beds may have been mud pellets from smoke-like clouds deposited along with the enclosing fine ash.

Many lenticular, stream-channel, and flood-plain deposits, ranging from tuffaceous sandstone to boulder conglomerate, are in the lower and upper parts of the formation. On the southeast side of Goat Mountain there are five sandstone-breccia-conglomerate beds 3–25 feet thick within the lower 214 feet of the section; the upper zone, 90 feet thick, is 240 feet below the top and appears to be more persistent than the lower beds. That these coarse-grained lenticular beds are stream-laid deposits is clearly shown by the poor sorting, rapid facies changes, scour-and-fill relations, and cross-bedding. The particles in the breccia and the conglomerate are syenite, trachyte, rhyolite, epidote rock, scoria, vesicular and dense basalt and andesite, and tuff. Many of the rocks probably originated in the Duff formation to the north; some could be from older flows in the Buck Hill succession, but others, for example the syenite and epidote rock, are not known in any contemporaneous or older formations in the area. Exposed syenite intrusions are younger than the Duff and could not have supplied gravel to its conglomerate members; therefore, either pre-Duff or contemporaneous intrusions must have been first eroded and then covered by younger effusive rocks.

Resistant clastic dikes of fine-grained tuff, 3–6 inches wide, are well developed in tuff beds at the head of Walnut Draw and in the southeast slope of Goat Mountain; some are traceable for more than 50 yards. Many show slickensides and brecciated surfaces, suggesting that they developed along joints as a result of small movements effected by major faulting near by. There are more or less complementary sets—one striking N. 70° W., the other N. 15° E.

The approximate boundary between distinctly southern and northern facies in the Duff formation lies in the latitude of Cathedral Mountain. To the south it is chiefly tuff with some sandstone, breccia and conglomerate, and thin basaltic lava flows. Flows increase in number, thickness, and kind to the north, and in the area southwest and west of the town of Alpine make up a large part of the formation. The Duff lava increases from about 150 feet thick in the east slope of Cathedral Mountain to more than 700 feet thick in the area west of McIntyre Peak.

The flows exposed in the east slope of Cathedral Mountain and southeast slope of Goat Mountain are olivine trachybasalt. Two flows are well exposed at Goat Mountain—one 10 feet thick and the other 40 feet thick are 330 and 800 feet below the top of the formation, respectively. The first unit has been highly affected by analcimization and zeolitization. Weathered zones contain much analcime as small euhedral crystals and crystal aggregates in cavities, cracks, and fissures, and especially along horizontal planes between thin sheets of basalt separated by weathering processes. It is most abundant and appears to be forming in moist areas where there is seepage along the sheetlike jointing planes. Some of the analcime is clear, but most is veneered with green opaque material, probably a mineral of the chlorite group. Long prismatic crystals of natrolite and fibrous radiating crystals of thomsonite—the two commonly intergrown and penetrating clear calcite crystals—are common in amygdaloidal cavities and veins in association with unidentified zeolites and abundant calcite. Solutions causing the analcimization and zeolitization probably came up along the Walnut Draw fault and spread into the Duff lava flows.

Thin sections show that the two flows are much alike, except for degree of secondary alteration. The primary minerals are more severely attacked by analcime and zeolites in the lower unit. The texture of the groundmass is between diabasic and trachytic. Labradorite laths and phenocrysts are mantled with alkalic feldspar; the ratio of calcic feldspar to alkalic feldspar is about 3:1. Before alteration, the total feldspar content was 65–70 per cent of the rock. Olivine and its alteration products, iddingsite, antigorite, and chlorite, account for 10–15 per cent of the volume (nearly all the olivine has been altered). Augite and magnetite each make up about 5 per cent, and apatite in the form of slender needles is an important accessory. Analcime, zeolites, and calcite are abundant secondary minerals. In the lower flow, analcime and zeolites have largely replaced feldspar and other minerals and constitute as much as 20 per cent of the rock.

DECIE MEMBER: The northern facies of the Duff differs from the southern facies in that the effusive rocks are predominantly rhyolite, trachyte, and trachyandesite, whereas flows in the southern part are chiefly trachybasalts. A succession which appears to constitute more than half the Duff formation in the Paisano Peak quadrangle, is designated the Decie member (Tdd on map, Pl. 1), named for exposures on the Decie ranch near McIntyre Peak in Cathedral Mountain quadrangle. These flows moved in from the north and northwest; the southernmost tongue, a trachyte porphyry that reached a point west of Haley Mountain, is about 60 feet above the base of the Duff and is 60–110 feet thick west of Haley Mountain and along the west side of the McIntyre Peak intrusive mass. A second tongue, a rhyolite porphyry, crops out around the east and north sides of McIntyre Peak. Deformation around the McIntyre Peak intrusive mass prevents determination of exact stratigraphic relations, but the base of the rhyolite appears to be approximately 150 feet above the base of the Duff with a maximum thickness of 237 feet. A few miles north and northwest of McIntyre Peak the Decie is a thick succession of flows of rhyolite, trachyte, trachyandesite, and massive flow breccias.

The rock comprising the lower trachyte flow is a fine- to medium-grained porphyry with many glassy phenocrysts of albite. The fresh rock is yellowish brown and the weathered lava is light chocolate brown. Thin sections reveal a fine granular groundmass, 75–85 per cent alkalic feldspar, enclosing numerous albite phenocrysts of various sizes and shapes—squarish, rectangular, lath-like, and irregular, some more than 5 mm long. Magnetite and its alteration products, limonite and hematite, constitute 1 per cent; pale lead-gray augite, 2 per cent; light-brown sodic hornblende, possibly kataphorite, 2 per cent; and light dark-brown biotite, 2 per cent; olivine (mostly altered) and its alteration products, iddingsite, bright-green chlorite (?), and antigorite, 10–15 per cent; apatite is an important accessory. The rock is an olivine trachyte porphyry.

The upper flow is a fine-grained, grayish-pink porphyritic rhyolite. Thin sections show a spherulitic-trachytic groundmass composed largely of feldspar microlites and interstitial quartz enclosing many square phenocrysts of anorthoclase, many of which show well-developed quadrille structure. The constituent minerals and their estimated percentages are: feldspar, 70 per cent; quartz, 15 per cent; magnetite and limonite, 4 per cent; iddingsite and chlorite, 5 per cent; apatite, trace; riebeckite, traces in patches of altered iron oxide.

Mitchell Mesa welded tuff.—Goldich and Elms (1949, p. 1161) named the thin cap rock of Mitchell Mesa in northwestern Buck Hill quadrangle the Mitchell Mesa rhyolite. This rock is similar to "ignimbrite" and "welded tuff" described by Marshall (1935), Mansfield and Ross (1935), Gilbert (1938), and others.

Following Fenner (1948, p. 883), Erickson (1953, p. 1376) described the Mitchell Mesa "rhyolite" as a "tuff-flow". Fenner differentiated "welded tuff" and "tuff-flow" on the basis of the degree of "welding".

Perhaps a name that indicates the degree of welding is desirable, but the method of emplacement of such deposits opposes use of the term "flow". *Nueés ardentes* is a suitable name for the "flowing" material. Presumably, there is no mass flowage once the material has been deposited, so that the term "ignimbrite", or preferably "welded tuff", would best apply to deposits of *nueé ardente* origin.

From 30 to 60 feet of the Mitchell Mesa welded tuff forms a resistant cap rock over all of Mitchell Mesa, except where it is breached by streams and many normal faults. It is well exposed in escarpments bounding the mesa on all sides and along arroyos and in fault-line scarps on top. Not restricted to Mitchell Mesa, it forms a well-developed bench about 700 feet above the base of each mountain in Goat and Cathedral mountains. The formation also caps and forms cliffs around three narrow buttes extending in a line northwestward from Cathedral Mountain to a point west of McIntyre Peak—the northernmost known outcrop.

In addition to outcrops in Buck Hill, Jordan Gap, and Cathedral Mountain quadrangles, and the southwest quarter of the Alpine (30-min.) quadrangle, the formation crops out over about 35 square miles on Bandera Mesa in Tascotal Mesa quadrangle (Erickson, 1953, p. 1364) and a sizable area occurs near the town of Shafter in Shafter quadrangle (Rix, C. C., 1953, PhD. dissertation, Univ. Texas); it caps small outliers near Fresno mine on the southwest side of the Solitario dome in Terlingua quadrangle, and similar rock is reported in Agua Fria quadrangle (Moon, 1953).

The thickness is uniform over a wide area. From Bandera Mesa in the south to the northernmost exposure in the Cathedral Mountain quadrangle it forms the cap rock on mesas, buttes, and other erosional remnants that averages 60 feet thick—ranging from 28 to 75 feet. Where it is overlain by the Tascotal tuff and exposed in cliffs in the sides of Goat and Cathedral mountains, it is 58–134 feet thick, averaging about 85 feet. Although a swell-and-swale topography tends to develop, the surface undergoing erosion remains nearly level. Columnar jointing is well developed in the rock, and the margins of outcrops are always precipitous.

Lithologically, the Mitchell Mesa welded tuff is the most distinctive unit of the Buck Hill succession. Much of the weathered rock is dark reddish gray but ranges from greasy black to reddish gray. On weathering, small pyramidal quartz and opalescent tabular feldspar phenocrysts stand out from the fine-grained groundmass; in many places the weathered surface is pitted and cavernous. Slightly elongated, vesiclelike cavities scattered through the rock contain soft ashy material, and, locally, fragments of hard "baked" tuff are incorporated in the matrix. Except for a thin layer (up to 2 feet thick) of loose material with the same composition as the welded portion at the bottom, and thin discontinuous areas of similar material on top, the rock is coherent—tough to brittle, and breaks with even to subconchoidal fracture.

The groundmass is composed of shards of pinkish to white, fine-grained rhyolitic glass and its devitrification products, and quartz and alkalic feldspar enclosing phenocrysts of quartz and feldspar. The feldspar (2V = about 35°) is intermediate between sanidine and anorthoclase, but faint quadrille twinning on a few of the phenocrysts suggests closer affinity with anorthoclase. Accessory and secondary minerals, present in minor amounts, include magnetite, zircon, biotite, apatite, hornblende, limonite, hematite, leucoxene, calcite, and chalcedony. Both the quartz, and the feldspar phenocrysts have irregular margins due to magmatic resorption; most of the phenocrysts do not exceed 5 mm in length. The glassy groundmass exhibits a vitroclastic "flow" structure.

Tascotal formation.—The Tascotal formation lies on the eroded surface of the Mitchell Mesa welded tuff and is overlain by flows of the Rawls basalt. It was named by Goldich and Seward (1948, p. 21) for Tascotal Mesa in Tascotal Mesa quadrangle where it is represented by approximately 800 feet of tuff, tuffaceous sandstone, breccia, and conglomerate. Erickson (1953, p. 1365–1366) mapped Tascotal Mesa quadrangle and found that the formation contains one basalt flow of small areal extent and lenticular beds of limestone. The formation can be followed continuously from a point 6 miles south of the town of Marfa across southwestern Alpine (30-min.), Jordan Gap, and Tascotal Mesa quadrangles to the northern rim of the Solitario dome, an airline distance of 48 miles.

Except for a few small conical outliers, it has been eroded from Mitchell Mesa. The only important outcrops in the Cathedral Mountain quadrangle are in the steep slopes of Goat and Cathedral mountains, between the Mitchell Mesa welded tuff bench and the Rawls basalt cap. There are four small outliers on the buttes extending northwestward from Cathedral Mountain.

The formation is thickest in the Jordan Gap-Tascotal Mesa area, where it reaches more than 900 feet; the maximum in Cathedral Mountain quadrangle, at the east end of Cathedral Mountain, is 462 feet. The thickness varies considerably within short distances, for example, it is 190 feet near the middle of the south side of Goat Mountain, 280 feet at the west end, and 334 feet at the east end. The average thickness on Goat Mountain is 268 feet as compared with an average of about 370 feet on Cathedral Mountain. It thins rapidly to the north, for in two small outliers capped by Rawls basalt on the butte west of McIntyre Peak, the northernmost outcrop, it is only 50 feet.

The formation is composed of light-gray and yellow sandy tuff, coarse sandstone, and pebble conglomerate. The pebbles are basalt, trachyandesite, and fine-grained syenite. Along the upper contact is a zone, 1–2 feet thick, of pink to red, fine-grained, baked tuff. The best outcrop in the area is at the east end of Cathedral Mountain in a nearly vertical cliff approximately 100 feet high. This exposure shows thick beds of yellow tuff and tuff breccia containing large angular blocks of basalt and conglomerate. Outliers on the buttes northwest of Cathedral Mountain contain light-gray, medium-grained, compact tuff, coarse to very coarse sandstone composed of clear grains of quartz, many of which are small pyramidal crystals, and pebble conglomerate cemented with a mixture of coarse sand and tuff. A zone of pinkish baked tuff beneath the upper contact is very hard and breaks with a conchoidal fracture.

Rawls basalt.—The youngest formation in the Buck Hill series, a succession of interfingering flows of trachybasalt and trachyandesite, with interbeds of tuff, tuff breccia, sandstone, and conglomerate, overlying the Tascotal formation, was named the Rawls basalt for the Rawls ranch on Tascotal Mesa by Goldich and Seward (1948, p. 22). It is extensive in southwestern Tascotal Mesa quadrangle, where it attains a thickness of 937 feet on LaMota Mountain (Erickson, 1953, p. 1369), and it extends into Polvo, Shafter, and Marfa quadrangles.

In the Cathedral Mountain quadrangle, the Rawls basalt has the same general distribution as the Tascotal formation—in small outliers on Mitchell Mesa and on a butte west of McIntyre Peak and over the summit areas of Goat and Cathedral mountains. The average thickness on Goat Mountain is about 270 feet, ranging from 150 to 370 feet, and on Cathedral Mountain, about 450 feet, ranging from 380 to 545 feet. On two small outliers on the butte west of McIntyre Peak, the northernmost exposure, the thickness is 30 and 75 feet respectively. The erosional remnants on Goat and Cathedral mountains are considerably thicker than on adjacent, structurally lower Mitchell Mesa and buttes. Also, the underlying Tascotal formation is thicker on these mountains than on the mesa and buttes.

The thicker sections on the mountains are made up of at least two flows of trachybasalt, each of which contains zones of coarse flow breccia. There are no tuff, sandstone, or conglomerate interbeds. The lower flow is very fine-grained, nonporphyritic, grayish-black basalt; the upper lava capping the highest summits on Goat Mountain is similar to the lower rock but is slightly coarser grained and porphyritic. The massive flow breccias are composed of an agglomeration of angular fragments, ranging from a fraction of an inch to more than 3 feet in diameter, "welded" into very coherent and resistant masses. The flow-breccia zones contain much black chalcedony in the form of botryoidal lining in cavities and coatings around blocks and in veins and stringers interlacing the breccia. Many cavities in the rock are lined with drusy quartz.

The lower lava is composed of a matte of tiny labradorite laths, mantled with alkalic feldspar, in well-developed flow alignment. The alkalic to calcic feldspar ratio is about 1:1, and feldspar accounts for 75–80 per cent of the volume. Magnetite-limonite and iddingsite (after olivine) each constitutes about 5 per cent of the rock. Interstitial to the feldspar, in a pattern similar to augite in other basalts in the area, are many small grains of slightly pleochroic, yellow to reddish-brown pyroxene (?) which has high relief, moderate birefringence, high dispersion, negative elongation, and a small extinction angle. Other minerals present in minor amounts include apatite, chlorite, antigorite, leucoxene, and analcime.

The upper basalt is diabasic and porphyritic and contains many small prismatic and irregularly embayed phenocrysts of labradorite mantled with alkalic feldspar. Approximate alkalic to calcic feldspar ratio is difficult to determine because the feldspars are so severely attacked by analcime and zeolites. The original feldspar content was probably 60–70 per cent of the rock, but analcime and zeolites have replaced feldspar to make up about 20 per cent of the volume. Slightly pleochroic augite and magnetite-ilmenite each account for approximately 10 per cent. Olivine, originally about 5 per cent of the rock, has been completely altered, principally to iddingsite. A green chloritic (?) mineral forming a coating around analcime and patches of zeolites is fairly abundant; secondary calcite is common.

Age and correlation.—The writer has established an Eocene age for the Pruett tuff by vertebrate fossils collected from localities in the Cathedral Mountain quadrangle and in the northern Buck Hill quadrangle. Material obtained in 1951 from a breccia-conglomerate 60 feet below the top of the Pruett tuff on a small hill near Cottonwood tank on the 02 Ranch in northern Buck Hill quadrangle (Goldich and Seward, 1948, Stop 5, p. 30) was studied by John A. Wilson, The University of Texas, who stated:

"The titanothere lower jaw from the Cottonwood tank locality agrees very closely in evolutionary development with a specimen in the collections of the Bureau of Economic Geology of The University of Texas from the lower part of the Vieja series near Porvenir, Presidio County, Texas."

Stovall (1948) described a suite of fossil vertebrates including titanothere collected from tuff beds beneath the quartz pantellerite run rock, in the lower part of the Vieja series (Vaughan, 1900), near Porvenir—the same beds from which the titanothere specimen in the collections of the Bureau of Economic Geology was obtained. Stovall assigned the assemblage a Chadron (lowermost Oligocene) age. In 1946, collections containing a large mammalian fauna were made from the same tuff unit by Bryan Patterson and James H. Quinn of the Chicago Natural History Museum. Patterson considered the fauna equivalent to that of the Chadron formation (Goldich and Elms, 1949, p. 1144). John A. Wilson noted:

"This fauna was identified as Duchesnean (oral communication) by Patterson. There has been controversy as to the age of the Duchesnean, but at a meeting of the stratigraphic committee in Boston, 1952, it was placed in the upper Eocene. Therefore, it seems safe to assume that, on present evidence, the Pruett tuff (lower part of the Pruett formation as defined by Goldich and Elms) and the lower part of the Vieja series are about the same age—Duchesnean or uppermost Eocene."

Vertebrate fossils indicate that the Pruett tuff (restricted) is approximately the same age as the Huelster formation of the McCutcheon volcanic series in the Barrilla Mountains and the lowermost tuff beds in the Vieja series in western Presidio County, Texas. A rhinoceros tooth collected by Baker (1935, p. 151) from tuff beds within 200 feet of the base of the McCutcheon series (Huelster formation), on the Casey ranch 11 miles east of Balmorhea, was identified by R. A. Stirton as *Hyracodon.* Remains of this genus were also obtained from the lower tuff beds in the Vieja series.

Using fossil plants, Berry (1919, p. 1–9) assigned an early Eocene or Paleocene age to what is now known as the Huelster formation, but the *Hyracodon,* a more reliable index, indicates later Eocene.

Following eruption of the Crossen trachyte there was a long period of erosion which produced a hill-and-valley topography on the trachyte surface; in a few places valleys were cut through into the underlying Pruett tuff. The top of the Eocene is placed at this important unconformity.

Overlying the tuff from which vertebrates were collected in the Vieja series is an acidic flow, similar to the Crossen trachyte, described by E. C. E. Lord (1900, p. 90–95) as quartz pantellerite. Possibly the Crossen trachyte and the quartz pantellerite (Rim Rock) are equivalent in age. Overlying the Huelster formation in the McCutcheon series is a succession of acidic flows named the Star Mountain rhyolite by Eifler (1951, p. 345). The Crossen trachyte is possibly equivalent to the lower part of the Star Mountain rhyolite.

The top of the Eocene is arbitrarily placed at the top of the Crossen trachyte, and, although no fossils reliable for age determination have been found in the succession above the Pruett tuff (restricted), the Volcanic rocks above the Crossen trachyte are shown (Pl. 1) as Oligocene and younger (?).

A period of dominantly acidic volcanism ended with eruption of the Crossen trachyte. The next outpourings produced basalts, trachybasalts, and trachyandesites which make up the Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt. Thin layers of limestone and/or tuff separate flows of Sheep Canyon basalt. At the top of the Sheep Canyon basalt and the Potato Hill andesite are thick weathered remnants of tuff-like decomposed lava produced by weathering. Much Cottonwood Spring basalt was removed by erosion before it was covered by the Duff formation. At least three limestone interbeds and deeply weathered, eroded surfaces in this group indicate a long time—perhaps all of the Oligocene. The Sheep Canyon basalt-Potato Hill andesite-Cottonwood Spring basalt succession is possibly equivalent to the upper two-thirds of the Star Mountain rhyolite in the Barrilla Mountains.

Goldich and Elms (1949, p. 1143–1146) tentatively assigned their Pruett formation (which included Pruett tuff, Crossen trachyte, Sheep Canyon basalt, and Potato Hill andesite) to the Eocene. This was based on the gastropod *Goniobasis tenera carterii* (?) which is abundant in limestone lentils in the Pruett tuff and Sheep Canyon basalt. But the stratigraphic ranges of Tertiary nonmarine and terrestrial gastropods are not well enough established for reliable correlation and close age determination.

After a long period of erosion which removed much of the Cottonwood Spring unit, a new volcanic cycle produced the enormous quantity of rhyolitic pyroclastic material found in the Duff formation, Mitchell Mesa welded tuff.

and Tascotal formation. Many lenticular stream deposits and lentils of nonmarine limestone at different horizons in the Duff and Tascotal formations show that the eruptions were intermittent over a long period of time. Possibly this group is Miocene.

The Duff formation was assigned to the Oligocene and correlated with lower Vieja tuff beds by Goldich and Elms (1949, p. 1144–1145) largely on the basis of a small gastropod associated with *"Helix" hesperarche* at Church Mountain and other places in Jordan Gap quadrangle. It was thought to be the same species, *Mesodon ("Helix") leidyi* (Hall and Meek), as that found with vertebrates in tuff of the lower Vieja series. Since it occurs in both Eocene and Miocene beds (Henderson, 1935, p. 134) this species cannot help differentiate the two units. More recently, vertebrate fossils found in the Pruett tuff have proved **that** the Pruett tuff (restricted) and the lower tuff of the Vieja series are equivalent. Perhaps the lower part of the Duff formation (Decie member) is equivalent to the Seven Springs formation of the McCutcheon series.

Following deposition of the Tascotal formation, a period of less explosive volcanic activity produced a succession of basaltic, trachybasaltic, and trachyandesitic flows—the Rawls basalt, youngest unit of the Buck Hill volcanic series. Basaltic lavas of Pliocene and Quaternary ages are known in south-central and southwestern New Mexico, and the Rawls basalt may have poured out in late Tertiary time—possibly in early Pliocene. The Buck Hill series probably is in part equivalent to the Square Peak series (Huffington, 1943) in the northern Quitman Mountains in Hudspeth County and to a very thick section known from oil test cuttings near Valentine in Jeff Davis County (Woodward, J. E., 1953, M.A. Thesis, Univ. Texas). The Chinati Mountain series in the Chinati Mountains, Presidio County, may be the same age as the Rawls basalt (Rix, C. C., 1953, Ph.D. dissertation, Univ. Texas). The Square Peak series, approximately 3500 feet thick, rests on Cretaceous sedimentary rocks (upper Washita) and is composed of alternating tuff, basalt, andesite, quartz latite, trachyte, rhyolite, and flow breccia. The more than 6000 feet of lava and pyroclastic material penetrated in the Valentine well resembles the succession found in the Buck Hill and McCutcheon series. The Valentine sequence probably includes equivalents to all Buck Hill units and some younger than the Rawls basalt. The Vieja series exposed in the Tierra Vieja Mountains dips toward the Valentine basin and may represent the basal part of the Valentine succession.

INTRUSIVE IGNEOUS ROCKS

General

The total surface area of intrusive rock in the Cathedral Mountain quadrangle is approximately 23 square miles—a little more than a tenth of the area. Individual exposures range from a few square feet to more than 12 square miles. Laccolithic bodies (deroofed trapdoor domes), plugs, sills, dikes, and one volcanic vent are represented. Similar intrusions are even more abundant in the central part of the northern half of the Alpine (30-min.) quadrangle. Except for the volcanic vent, which is made up of vent agglomerate, the intrusive masses are alkalic syenite.

Sills and Dikes

Erosional remnants of thick sills form the cap-rock of Elephant Mountain, the large mesalike mountain in the southeast corner of the quadrangle, and of Haley Mountain in the north-central part. A sill is exposed on the upper slopes of the line of buttes extending northwest of Cathedral Mountain, and the extensive, low outcrops of intrusive rock west and northwest of Cathedral Mountain probably represent sills, the bases of which are not exposed.

Dikes are common and conspicuous in the central part of the northern half of the Alpine (30-min.) quadrangle (around Paisano Peak, Twin Sisters, and Mitre Peak) but not in the Cathedral Mountain quadrangle. Narrow discordant "feeders" occur on the northern sides of Elephant and Haley mountains.

ELEPHANT MOUNTAIN SILL: The sill capping Elephant Mountain covers an area of 4.8 square miles. Its thickness is about 600 feet at the north end, nearly 1100 feet in the middle portion along the west side, and approximately 850 feet at the south end of the mountain. Well-developed columnar jointing aids in the formation of prominent cliffs around the margins. Marginal fragmentation results in thick talus accumulations on the steep slopes below. Two feeders are well exposed on the north side of the mountain, one near the middle and the other at the northeast corner. They are narrow dikelike bodies continuous with the sill, cutting through the underlying layered volcanic rocks and disappearing under the alluvial cover in the valleys at the base of the slope. These feeders were probably from a very large intrusive mass underlying the low area immediately north of the mountain. That such a mass existed is indicated by three small outcrops of syenite in that area, which are probably bosses on the same body. The bosslike nature of one of the outlying outcrops, the one nearest the mountain, is shown by the doming of Pruett tuff beds and Boquillas flags in a small area around the exposed core of syenite. The large buried mass may also extend under the whole mountain because the faulting of the volcanic layers beneath the sill suggests deformation produced by intrusion of an underlying igneous body.

The structural relationship between the sill and the underlying rocks is important to the present topography. Beginning at the westernmost feeder and continuing along the west side and around the south end of the mountain, the sill rests on flows of Sheep Canyon basalt, while eastward from this feeder and along most of the east side it overlies Pruett tuff. The Crossen trachyte is absent, having been removed by erosion before the Sheep Canyon basalt flowed out over the Pruett tuff. The tuff and lava are strongly tilted away from the feeder on the west side. As the upper surface of the sill (present mountain summit) has two general levels, with the highest part over the western half where the sill is underlain by the Sheep Canyon basalt, it appears that the magma came up along a major fissure trending northwest-southeast and spread laterally at two different horizons—northeastward along the Pruett tuff-Sheep Canyon contact, and southwestward along the Sheep Canyon basalt-Potato Hill andesite contact. Emplacement of the thick sill along the Pruett tuff-Sheep Canyon basalt contact elevated the Sheep Canyon basalt and overlying rocks on the northeast side of the feeding fissure, but only Potato Hill andesite and younger rocks were raised on the southwest side. When all overlying rocks were removed by erosion the two-level surface of the sill was exposed. There were probably other feeders to each horizon; the one at the northeast corner of the mountain is continuous with the part of the sill that rests on the Pruett tuff.

HALEY MOUNTAIN SILL: A slightly discordant, tabular mass approximately 300 feet thick is exposed over 0.44 square mile and forms the upper portion of Haley Mountain. The base dips 4° NW. and cuts across Duff tuff and Cottonwood Spring basalt which dip a little more west of north about 3°. The intrusive sheet rests on basal Duff tuff on the east, south, and west and on Cottonwood Spring basalt on the north side of the mountain. A narrow dike cuts obliquely across the underlying volcanic rocks in the north slope. Curved, dikelike prongs enclosing a pocket of Duff and Cottonwood Spring rocks on the west side probably are not true dikes but ridges on the irregular upper surface of the sill.

Haley Mountain is a small erosional remnant with steep slopes on the north, east, and south. The area now covered by the capping sill probably is only a fraction of the original.

SILLS WEST AND NORTHWEST OF CATHEDRAL MOUNTAIN: Tabular sheets apparently spread out in all directions from a feeder exposed in the gap between the first and second buttes northwest of Cathedral Mountain. A southward extension is exposed in the upper slopes on either side of the northern part of the first butte. It intrudes the upper Duff formation discordantly, dipping 4° SE. Northward from the feeder, a more horizontal sheet is well exposed in the upper slopes of the second (middle) butte, in the low area between the second and third buttes and in the upper slopes around the south end of the third butte. It averages 80 feet thick, but both the top and bottom are irregular, and thickness ranges from 50 to 110 feet. This sill is continuous with a low, hilly outcrop of intrusive syenite covering nearly 3 square miles in the flat west of the line of buttes (mostly on the 101 Ranch). Erosion has exposed the upper surface but not the base; because sill relationships are shown in the slopes of the buttes the entire mass is believed to be a sill. Small isolated knobs sticking up through the alluvial cover are probably local highs of the same sill. An extensive outcrop of intrusive rock with similar surface expression in the same broad flat west of Cathedral Mountain is interpreted as a sill associated with the huge Cienega Mountain intrusion. All these sills cut the upper part of the Duff formation.

Laccolithic Bodies and Plugs

Two deroofed masses of general laccolithic type, the Cienega Mountain and McIntyre Peak intrusions, account for more than half the total outcrop area of intrusive rocks. Of the two, the Cienega Mountain mass comes closer to being a true laccolith, but neither shows completely concordant relations. Part of the Cienega Mountain mass is similar to trapdoor domes described by Knechtel (1944) and Moon (1953), except that faulting is obscured by the intrusion itself. The McIntyre Peak body is more complex, showing features of both a trapdoor dome and a plug.

CIENEGA MOUNTAIN INTRUSION: A continuous outcrop of intrusive rock from Little Cienega Mountain to Cathedral Mountain covers 11.2 square miles. Including isolated exposures near by, the total outcrop area of the Cienega Mountain mass is 12.4 square miles. The major part of the exposed mass forms the large dome-shaped Cienega Mountain. Little Cienega Mountain is a boss on the main body at the southwest corner of the exposed portion, and similar protuberances occur along the southeastern margin of Cienega Mountain. Plugs at the northeast end of Goat Mountain, near the marble quarry on the east and north sides of Cienega Mountain, and lesser exposures west of Cienega Mountain, although not visibly connected, are believed also to be "bumps" on the Cienega Mountain mass. The central part of the Cienega Mountain intrusive mass arched Cretaceous sedimentary beds and layers of Tertiary volcanic rocks on the northwest side of the mountain. Erosional remnants of basal Cretaceous sandstone and conglomerate on the mountain top indicate that the beds dipping off the northwest slope once extended over the summit. Along the base of the west slope the intrusive mass is in contact with steeply tilted Tertiary volcanic rocks. On the south side are small pockets of Cretaceous limestone and Tertiary volcanic rocks dragged up by the intrusion, but the main exposed contact is between the intrusion and slightly tilted volcanic rocks of the upper part of the Tertiary section (Cottonwood Spring basalt)—a relation which holds around the east base of the mountain. The igneous core is in contact with the Duff tuff on the northeast side. Contact relationships present Cienega Mountain proper as an eroded trapdoor dome in which the intrusive core raised the "door" so high that parallel faults on the northeast and southwest sides and the end fault across the southeast side were obscured by the intrusive mass.

The larger mass which includes Cienega Mountain cannot be fitted into the trapdoor dome category. That part exposed around the south side of Cathedral Mountain is beyond the limits of the dome. As was suggested, the wide outcrop west and southwest of Cathedral Mountain may be a sill-like expansion of the body, but exposures immediately south of it are not sill-like. The complex faulting of the volcanic layers in Cathedral Mountain strongly suggests a large irregular intrusion at a shallow depth. The greater Cienega Mountain intrusion must be a complex body with the proportions of a large stock.

MCINTYRE PEAK INTRUSION: McIntyre Peak is a high conical protuberance on a larger mass exposed over 1.5 square miles in the north-central part of the quadrangle. Many plugs, sills, and dikes in the area immediately to the north (southern part of the Alpine (15-min.) quadrangle) and the McIntyre Peak mass may all be parts of one large stock.

An uncovered, modified trapdoor dome adjacent to McIntyre Peak on the east indicates that a sizable portion of the intrusive body extends eastward below the surface. The portion of which McIntyre Peak is a part apparently pushed upward like a plug into overlying Tertiary volcanic rocks, breaking off, tilting, and elevating large blocks of volcanic rock.

The Haley Mountain sill is a remnant of a tabular offshoot from this mass.

EAGLE PEAK VOLCANIC VENT: Several plug-like peaks in the area resemble volcanic necks, but only Eagle Peak can be identified as a volcanic vent. This conical mass of vent agglomerate is only about 300 feet in diameter at the base and approximately 150 feet high and is situated alongside the Calamity Creek fault in the central part of the quadrangle. The rock is a well-cemented, fine-grained volcanic breccia composed of small to medium lapilli of basaltic and andesitic lava and fragments of baked tuff.

Distribution Pattern, Petrography, Relative Age

The intrusive masses in the Davis Mountains show alignment from Elephant Mountain on the southeast approximately N. 25° W. to Sawtooth Mountain and beyond on the northwest. They are especially numerous along either side of a line extending from Cienega Mountain to the northern boundary of the Alpine (30-min.) quadrangle, in an area about 30 miles long and 10 miles wide where larger masses include Cienega Mountain, McIntyre Peak, Ranger Peak, Twin Sisters Peak, Paisano Peak, Twin Mountains, the three Mitre Peak plugs, and Barrillos dome. Several lesser masses occur in the area immediately north of McIntyre Peak and around Twin Sisters Peak. The dose spacing of so many masses of mineralogically similar rocks suggests a common source, and perhaps they are all protuberances on one batholithic body underlying the area.

All intrusive igneous rocks exposed in the Cathedral Mountain quadrangle, except the vent agglomerate in Eagle Peak, are alkalic microsyenite. The syenite is remarkably uniform in composition. Except for the dark-green syenite sill on the 101 Ranch, the rock is light greenish gray, fine-grained, and even-textured. It weathers yellowish to reddish brown and breaks down by exfoliation and thin sheet jointing. Rare porphyritic zones contain small phenocrysts of anorthoclase, and flow structure is well developed in the basal parts of some of the sills.

Although thin sections reveal minor variations in mineralogical composition the following description fits the rock generally. The texture is slightly porphyritic, fine-grained, trachytic to granular. Alkalic feldspar constitutes 85–90 per cent of the rock. The feldspars are dusty, extinction in the laths is anomalous, and the twinning is indistinct. There are a few small phenocrysts of anorthoclase. Aegerine-augite is the most abundant mafic mineral, 5–10 per cent. Olivine, an original constituent in all the rocks, is altered completely to serpentine and iddingsite, 1–2 per cent. Apatite is an accessory, and a small amount of analcime is present in most samples. Secondary minerals include limonite, sericite, calcite, day minerals, and probably zeolites.

Analcime (up to 5 per cent) and calcite are more abundant in samples from Elephant Mountain than in any others. The Cienega Mountain rock contains 1–2 per cent quartz, interstitially and as small grains. The dark-green color of the 101 Ranch sill results from an even distribution of shreds of aegerine-augite in the groundmass (about 10 per cent of the rock).

Noselite (?), enigmatite, and riebeckite were found only in rocks from the McIntyre Peak-Haley Mountain mass and the mass underlying 101 Ranch. Small (up to 1 mm in diameter), dull-white, six-sided crystals of noselite (?) are conspicuous in syenite specimens from these areas. The mineral is isotropic, has an index of refraction of 1.485–1.490, and in nitric acid solution with barium chloride gives a white precipitate of barium sulphate. Most of the crystals are altered to sericite and probably zeolites, and many are rimmed with aegerine-augite and altered riebeckite.

The Elephant Mountain sill is younger than the Sheep Canyon basalt, but how much younger cannot be determined since the beds once above the sill have been removed by erosion. The Tascotal formation is cut by a portion of the Cienega Mountain intrusion; the faults affecting the Rawls basalt on Cathedral Mountain probably resulted from pressures exerted by the mass beneath the mountain. Intrusive rocks in the McIntyre Peak and 101 Ranch areas are younger than the Duff formation. Eagle Peak vent is surrounded by the Cottonwood Spring basalt, but, since it is on the Calamity Creek fault which cuts the Duff formation, it is probably post-Duff in age. The mineralogical similarity of all the syenitic rocks suggests a genetic relationship and contemporaneous intrusion. In the Cathedral Mountain quadrangle, all the intrusive bodies appear to be younger than the youngest volcanic rocks.

QUATERNARY SYSTEM

Local deposits of Quaternary age include talus and colluvium on the slopes and alluvium in the valley flats. Only the alluvium was mapped.

Albritton and Bryan (1939, p. 1423–1474) studied the valley fill in this area and on the basis of disconformities divided it into three formations, from oldest to youngest: (1) Neville, (2) Calamity, and (3) Kokernot. Type localities for these formations are in the Sheep-Calamity Creek valley west and northwest of Elephant Mountain. The formations are well exposed in stream banks and arroyos, but because the valley flats are unterraced the alluvium cannot be differentiated on a geologic map of the scale used.

The alluvium consists of poorly sorted materials ranging from clay and silt to boulders. Basal beds are more coherent and contain much secondary calcium carbonate as white nodules in the silt zones and as an encrustation around pebbles and cobbles in the conglomerates. Upper beds are less calcareous and contain more humic clay. A typical exposure shows 3–4 feet of clay and fine silt at the base overlain by an equal amount of sand and coarse gravel which grades upward into clay and silt containing scattered gravels. In most outcrops the thickness ranges from 10 to 15 feet, but 30 feet is exposed in places and as much as 50 feet has been penetrated in water wells. Conspicuous alluvial fans along tributary streams near the base of steep slopes facing major valleys, built up to a profile of equilibrium during the last period of aggradation, are being dissected at present.

Aquatic and land gastropods occur through all of the fill. Elephant remains have been found only in the lower portion (Neville). Upper beds contain artifacts, hearths, and human burials (Albritton and Bryan, 1939, p. 1172).

STRUCTURE

Five diastrophic events are recorded by structural features in the Cathedral Mountain quadrangle. Listed in chronological order these are:

(1) Tilting, uplift, and erosion of the Permian strata prior to the deposition of Comanche beds (post-Capitan, pre-Trinity)
(2) Folding, uplift, and erosion prior to deposition of the Pruett tuff (post-Boquillas, pre-Pruett; post-Cretaceous, pre-upper Eocene)
(3) Gentle tilting of Tertiary volcanic layers (post-Rawls basalt, pre-syenite intrusive activity)
(4) Local doming and faulting caused by intrusion of syenite bodies (post-Rawls, pre-normal faulting and pre-valley-fill; late Tertiary or early Quaternary ?)
(5) Normal faulting (post-syenite intrusive activity and pre-valley-fill; late Tertiary or early Quaternary ?)

That Mt. Ord and the northern Del Norte Mountains stood high at the beginning of Cretaceous deposition, possibly as a low asymmetric ridge connected with the Glass Mountains to the northeast, is shown by the fact that the Comanche Edwards limestone rests directly on the Permian Capitan limestone in that area, while at Cienega Mountain, 13 miles to the southeast, nearly 400 feet of sandstone and conglomerate of Cretaceous (Trinity ?) age underlies the Edwards. Furthermore, the distribution of basal Cretaceous formations in the Del Norte Mountains southward from Mt. Ord show that the Cretaceous sea gradually transgressed high ground in that area. Late Cretaceous, pre-upper Eocene Laramide folding is shown along the eastern margin of the area by the angular unconformity between the Cretaceous strata and the overlying Pruett tuff. South of Mt. Ord the Cretaceous beds dip generally 5°–10° W., but near Mt. Ord the strike changes gradually through 180° of arc around the west side of a domical structure athwart the Del Norte Mountains, and dips are as high as 35°. Strike changes and dip increases similarly along the west side of the broad Altuda dome at the north end of the Del Norte Mountains. Although dipping more gently, 2°–10°, the Tertiary volcanic layers reflect structure of the underlying Cretaceous beds, including the domes at Mt. Ord and Altuda Mountain.

Whereas the strike of the Cretaceous strata exposed along the west side of the Del Norte Mountains is generally north to northwest, the strike of the overlying volcanic rocks is north to northeast. But the strike changes in response to the Mt. Ord and Altuda domes. The gentle regional dip (2°–4°) is to the northwest. Locally, large stock-like intrusions (Cienega Mountain and McIntyre Peak masses) and faults have disturbed the regional trend. The regional dip is slightly altered on the faulted sides of the trapdoor domical portions of the Cienega Mountain and McIntyre Peak stocks, but steep dips extend away for considerable distances on the arched sides. All dips steeper than the average regional dip appear to be related to younger faulting or intrusive action. Since a core of intrusive syenite is exposed in the Altuda dome, the Mt. Ord dome could be the result of a buried laccolithic intrusion. If so, its last deformation may have occurred at about the same time the intrusions in the area were emplaced.

Probably the first folding of the Tertiary volcanic series began when the Duff formation was being deposited and continued through Tascotal time. Beds of coarse conglomerate are abundant in the Duff formation and even more so in the Tascotal formation. All observable intrusions in the area are younger than any of the volcanic rocks, yet conglomerate beds in the Duff formation contain syenite gravel. Perhaps folding was accompanied by intrusive activity. Also, the Tascotal formation where capped by the Rawls basalt on Goat and Cathedral Mountains is much thicker than in Rawls-capped erosional remnants on Mitchell Mesa and the buttes northwest of Cathedral Mountain. The Rawls basalt is considerably thicker on Goat and Cathedral Mountains than elsewhere in the quadrangle, in spite of the fact that both of these mountains have been elevated by faulting and subjected to an increased rate of erosion. A northeastward-trending basin probably existed in the area now occupied by Goat and Cathedral mountains when the Tascotal formation was being deposited and when the Rawls lavas spread over the area. Downwarping initiated in Duff time may have continued through Tascotal time. That the Mitchell Mesa welded tuff between the Duff and Tascotal formations shows no thickening in this area does not preclude the existence of a basin at that time. Being of *nueé ardente* origin, it was probably deposited in a uniform layer over hill and valley alike; no initial dips are apparent in this highly faulted area. But the tilted attitude of the Rawls basalt in Jordan Gap and Tascotal Mesa quadrangles shows that the major folding occurred after Rawls time.

Many normal faults are younger than the regional folding of the Buck Hill volcanic series. Eighteen of the 40 normal faults mapped are associated with igneous intrusions, and 15 occur along the western margin of Mitchell Mesa in the Walnut Draw fault zone. The three major faults, all with downthrow to the southwest, that extend northwest across the southern part of the quadrangle are Calamity Creek, Torvea Canyon, and Walnut Draw faults (Pl. 1).

The Calamity Creek fault enters the quadrangle from the south between Elephant Mountain and Calamity Creek and continues along the east side of the creek for 12½ miles to a point south of Haley Mountain. It strikes nearly north along the west side of Elephant Mountain and to a point northeast of Nevill ranch headquarters, then turns westward and trends N. 25° W. It is concealed by alluvium in Calamity Creek valley at the south end but can be followed easily northwestward from where it emerges from the valley. It crosses State highway No. 118 about 200 yards north of the Calamity Creek bridge, where the Cottonwood Spring basalt on the southwest side has been dropped down against the Crossen trachyte on the northeast. The amount of displacement varies (300–500 feet) along the fault but appears rather uniform as far north as Eagle Peak, from where it dies out rapidly.

The Torvea Canyon fault enters from the south in the southeast corner of the south-central quarter of the quadrangle, strikes slightly north of west through Torvea Canyon across Crossen Mesa and then follows a sinuous course trending N. 28° W. to a point southwest of Little Cienega Mountain, a distance of about 6 miles. Displacement increases from about 150 feet at the east-facing escarpment of Crossen Mesa to 300–400 feet at the west side of the mesa and then gradually decreases northwestward.

The Walnut Draw fault crossing the southwestern part of the area is the master fault of the Walnut Draw fault zone. It can be traced southeastward across Buck Hill quadrangle and into Santiago Peak quadrangle (Goldich and Elms, 1949, p. 1170). It follows Walnut Draw into the Cathedral Mountain quadrangle and continues N. 15° W. along the east side of Mitchell Mesa and the west end of Goat Mountain. The Walnut Draw fault zone is part of a system of northwest-trending faults developed along the northeast flank, roughly parallel to the axis, of a broad northwest-plunging nose in the Buck Hill volcanic series extending across western Buck Hill and northern Jordan Gap quadrangles (Goldich and Seward, 1948, Fig. 3). The highly faulted eastern margin of Mitchell Mesa lies within the Walnut Draw fault zone.

Displacement along the main Walnut Draw fault is about 450 feet in the southern part of the Cathedral Mountain quadrangle, but the cumulative stratigraphic throw in this area is between 850 and 1000 feet (structure section D–D′, Pl. 1). At the west end of Goat Mountain the vertical separation is 650–700 feet. The main branch faults cutting Mitchell Mesa have a strong northwesterly trend and show displacements ranging from 50 to 200 feet; lesser faults strike in different directions. Several small horsts and grabens are present over the mesa. Minor faulting along the edges of escarpments probably resulted from landslides—toreva-blocks. Both obsequent and resequent fault-line scarps are prominent topographic features in Goat Mountain-Mitchell Mesa area. No actual fault scarps are present in the quadrangle.

Although the faults around Cienega Mountain and McIntyre Peak are obviously associated with intrusive igneous masses, and it is believed that the complex faulting around Cathedral and Elephant Mountains is the result of stresses set up by intrusive bodies beneath them, it is possible that two northwestward-trending faults transecting the lower southwestern slope of Elephant Mountain and two others that cut the northeast end of Goat Mountain are not effects of the local intrusion.

An important fault enters the quadrangle just north of Mitchell Mesa and west of the northwest corner of Goat Mountain (structure section D–D′, Pl. 1). This northeast-striking fault probably extends along the base of the northwest-facing escarpment of Goat Mountain (Pl. 3, fig. 1), but it cannot be traced in the tuff and alluvium. The base of the Rawls basalt on a small hill just outside the mapped area at the northeast corner of Mitchell Mesa is approximately 1150 feet lower than on the southwestern part of Goat Mountain, but 650–700 feet of this displacement was produced by the main Walnut Draw fault.

PHYSIOGRAPHY

The physiography or geomorphology of the Cathedral Mountain quadrangle deserves fuller treatment than can be given to it in a short chapter in a general paper of this kind. The primarily descriptive discussion which follows is designed to do little more than supplement the geologic map (Pl. 1) which lacks a contour base.

The rugged topography includes neck-like igneous peaks, steep cuesta escarpments, fault-line scarps (both obsequent and resequent), mesas and buttes, dissected mountainous divides and isolated rounded hills, dissected pediments and slopes, wide valley flats, and narrow, steep-walled canyons; depositional forms include talus deposits, alluvial fans, and alluviated valley flats.

One of the most prominent landmarks is Elephant Mountain in the extreme southeast corner, a high, somewhat rectangular, mesa-like erosional remnant covering approximately 16 square miles. Its fairly flat summit, about 4.8 square miles in area, stands from 1800 to 2000 feet above the wide valley of Calamity Creek on the west and south and about 1600 feet higher than Chalk Valley on the north. A nearly vertical cliff ranging from about 600 feet to more than 1000 feet bounds the summit and exposes the full thickness of the capping syenite sill. At the base of this escarpment along the west side, a slightly concave bench is well developed on basaltic lavas, and minor benches are developed on interbeds of tuff; faulting across the southwest slope has aided in the development of prominent benches there. The slope developed on the basaltic lavas underlying the cap-rock on the west side has a fairly uniform and steep grade (about 23 per cent). Slopes on the northeast and east sides of the mountain, on the Pruett tuff, are less steep and have a slightly concave profile; the lower portions on the tuff are dissected pediment surfaces. Headward erosion by the major consequent streams has produced several re-entrants in the cap-rock, especially on the east side. Large alluvial fans at the base of the slopes are now being dissected.

Lower mesalike areas—Crossen and North Crossen Mesas—lie across the wide flat valley of Calamity Creek and its tributaries to the west and north of Elephant Mountain. Except for a few scattered outlying low hills of younger lavas, the Crossen trachyte covers these areas, and the gentle northwestward dip of the surface is approximately the dip slope of that lava flow. Consequent (or resequent) streams have cut many shallow valleys into the lava. The relief almost nowhere exceeds 100 feet. Crossen and North Crossen "mesas" are bounded on the south and east by steep escarpments, 300 to 600 feet high (Pl. 3, fig. 2); the flat area ends on the west and northwest as the Crossen trachyte dips under younger volcanic rocks. The escarpment bounding Crossen Mesa on the south and east continues with few breaks from northern Buck Hill quadrangle to and beyond the northern boundary of the Alpine (15-min.) quadrangle; from North Crossen Mesa northward it forms the eastern boundary of the Davis Mountains. This escarpment is an erosional front of a succession of Tertiary volcanic rocks that once extended much farther south and east. The eastern escarpment increases in height toward the north because of structural elevation, standing more than 1000 feet above the valley of Maravillas Creek a short distance south of Mt. Ord. Cretaceous limestones (Boquillas, Buda, and Georgetown) are exposed in the lower part of the scarp in this area.

Mt. Ord, one of the highest summits in the Cathedral Mountain quadrangle (elevation 6850 feet), is a "cuesta" peak capped by Crossen trachyte. Tertiary volcanic layers are bowed around the west side of a large dome, the center of which lies about three-fourths of a mile east-northeast of Mt. Ord in Altuda and Monument Spring quadrangles in the Del Norte Mountains. The Crossen trachyte dips 6°–10° SW., W., and NW. as it bends around the dome. The lava cap breaks off abruptly on the east and northeast sides, surmounting a steep cuesta escarpment overlooking the Del Norte Mountains. Mt. Ord stands about 1800 feet above the bed of Ash Creek at the foot of the dip slope on the west side; the east-facing escarpment is approximately 600 feet high.

Consequent streams flowing down the southwest slope of the Mt. Ord structure cut down through the trachyte flow into Pruett tuff and breached the east-facing escarpment at three places immediately south of Mt. Ord, producing two isolated peaks and a third eminence at the south with steep slopes on the north and east. They also carved an elongated basin south of Mt. Ord and along the west side of the line of peaks.

About 8½ miles west of Mt. Ord are three conical peaks of intrusive syenite, all uncovered plug-like protrusions on the same igneous intrusion. The northernmost and highest, McIntyre Peak (elevation 6350 feet), stands 1200–1300 feet above adjacent stream valleys. An uncovered erosional remnant of a tabular southeastward extension of the same intrusive body now forms the protective cap on Haley Mountain. A buried "hump" on the intrusion produced a trapdoor dome along the east side of McIntyre Peak that presents a steep (18°–22°) generally eastward-dipping slope and a horseshoe-shaped fault scarp, 50–300 feet high, facing southwest, west, and northwest. The Crossen trachyte which forms the surface on this dome dips under younger lavas in a synclinal area to the east. That part of the igneous mass exposed, on which McIntyre and the two other peaks are surmounted, brought up a few large blocks of lava and tuff and left them resting at various angles, especially around McIntyre Peak. Rugged and highly irregular topography has resulted from erosion of this structurally complex area.

Across Calamity Creek from the McIntyre Peak-Haley Mountain igneous intrusive mass, a broad dissected pediment carved on tuff, sandstone, and conglomerate of the Duff formation rises gently to the base of the steep slopes of Cathedral Mountain and a chain of narrow buttes extending north-northwest from Cathedral Mountain. The great spire of Cathedral Mountain (Pl. 2, figs. 1, 2), an upthrown block of Rawls basalt (elevation 6860 feet), is about 2100 feet higher than the valley of Calamity Creek on the east and stands approximately 1800 feet above the eastern edge of the Marfa Plateau to the northwest. Cathedral Mountain is a rectangular-shaped erosional remnant composed of nearly horizontal layers of alternating tuff and lava which were uplifted and broken by numerous faults caused by the stock-like syenitic intrusion exposed in Cienega Mountain to the south.

The narrow flat-topped erosional remnant projecting north-northwest from Cathedral Mountain is capped by Mitchell Mesa welded tuff, with a few small conical outliers of Tascotal tuff and Rawls basalt. Headward erosion has breached this elongated remnant at two places, forming three separate buttes.

The largest area devoid of appreciable relief in the Cathedral Mountain quadrangle lies west of these buttes. It is the eastern edge of the Marfa Plateau, a broad flat area extending west and northwest to Marfa and beyond. Pediments developed on the Duff formation along the base of the slopes of the buttes on the east, Cathedral Mountain on the southeast, and Goat Mountain and Mitchell Mesa on the south dip under a veneer of alluvium a short distance away from the highlands.

Goat Mountain (Pl. 3, fig. 1) is a high, rectangular, block-like erosional remnant, elongated northeast-southwest, about 3 miles long and 1-1½ miles wide. Like Cathedral Mountain, it is composed of two thick tuffs alternating with two lavas, nearly horizontally disposed. Differential erosion has produced long steep slopes, vertical cliffs, and benches. The southwest and northwest fronts of the mountain are resequent fault-line scarps; the northeast and southeast faces are erosional escarpments. The summit area (elevation 6750 feet) is about 1750 feet above adjacent lowlands on the northwest and southeast and approximately 1400 feet higher than the general level of Mitchell Mesa to the southwest.

East of Goat Mountain and south of Cathedral Mountain, erosion of a complex trapdoor dome has exposed more than 13 square miles of intrusive syenite, the major portion of which (nearly 8 square miles) forms most of broad domical Cienega Mountain. Cretaceous sedimentary beds and Tertiary volcanic layers arched by the intrusion on the west and north have been truncated and shaped by differential erosion into a series of curving cuestas and hogbacks, especially along a northeast trend between Goat and Cathedral Mountains. There are several protuberances on the stock-like intrusion marginal to the Cienega Mountain portion, the most prominent of which is Little Cienega Mountain on the southwest side.

Southwest of Goat Mountain, between the Walnut Draw fault and the western boundary of the mapped area, lies the northeastern portion of Mitchell Mesa. The thick Duff tuff is overlain by a thin, more resistant layer of welded rhyolitic tuff (Mitchell Mesa welded tuff) which forms the cap-rock for the "mesa." This so-called mesa, bounded on the east by an obsequent fault-line scarp parallel to the Walnut Draw fault, is broken by many normal faults, most of which strike northwest, with small displacement—some downthrown to the northeast, others to the southwest. The height of the scarp is about 250 feet at the north end, 500 feet along the middle stretch, 800 feet overlooking Walnut Draw, and approximately 650 feet at the southern boundary of the quadrangle. Several small landslide blocks occur along the edge of the escarpment.

South of Goat Mountain, between the graben occupied by Walnut Draw and Goat Creek, a rough well-dissected terrain developed largely on the Cottonwood Spring basalt slopes gently

PLATE 2.—VIEWS OF CATHEDRAL MOUNTAIN

FIGURE 1.—Rawls basalt, spire and upper bench of Cathedral Mountain. View northeastward
FIGURE 2.—Cathedral Mountain. View southwestward from the Brown ranch

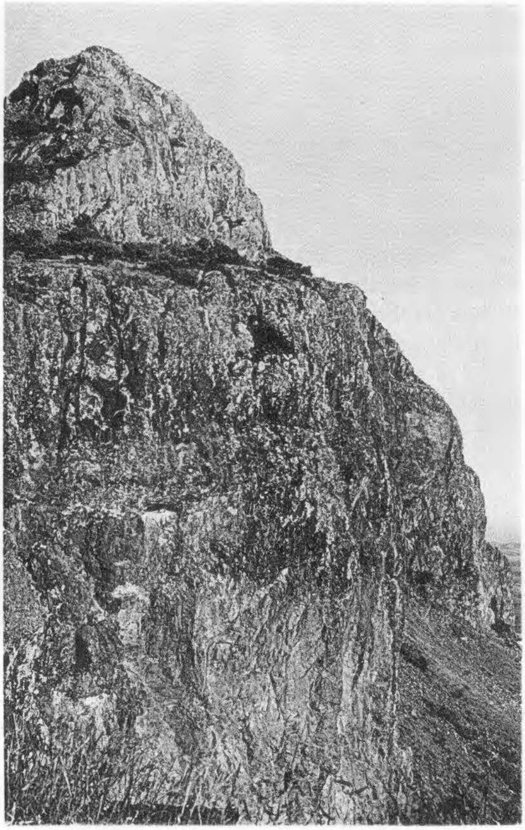


FIGURE 1

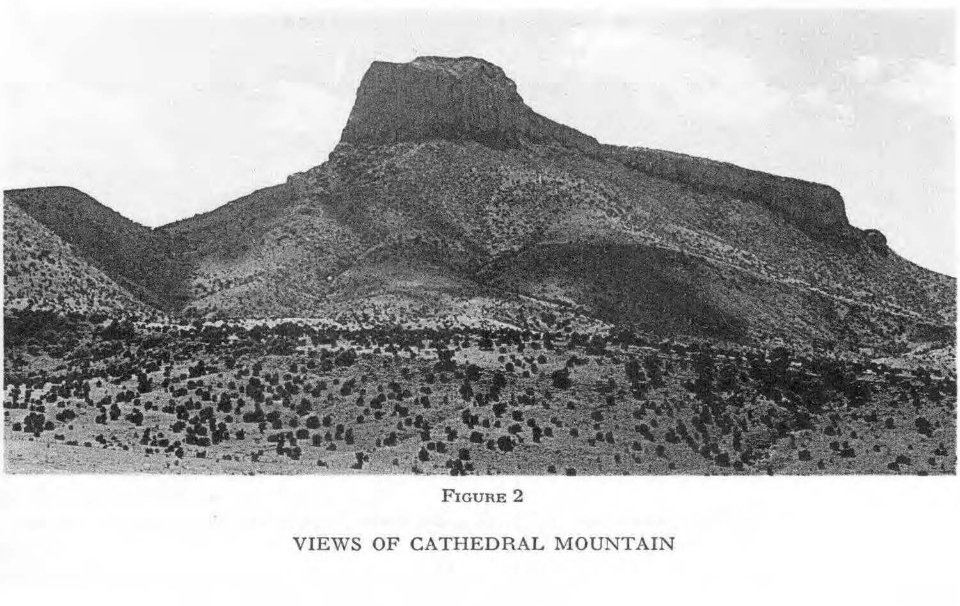


FIGURE 2

VIEWS OF CATHEDRAL MOUNTAIN

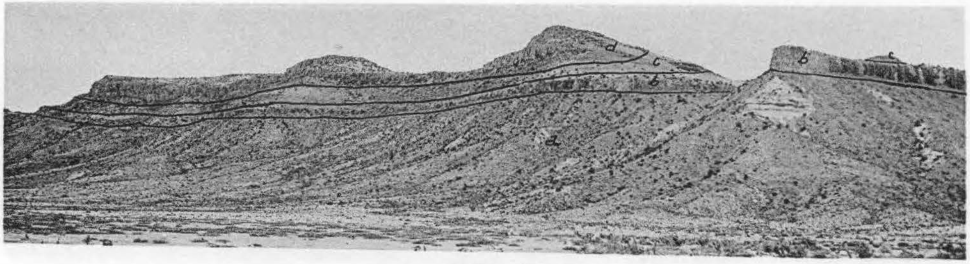


FIGURE 1

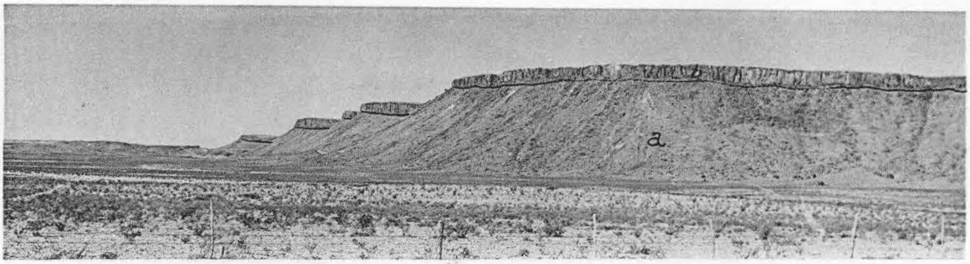


FIGURE 2

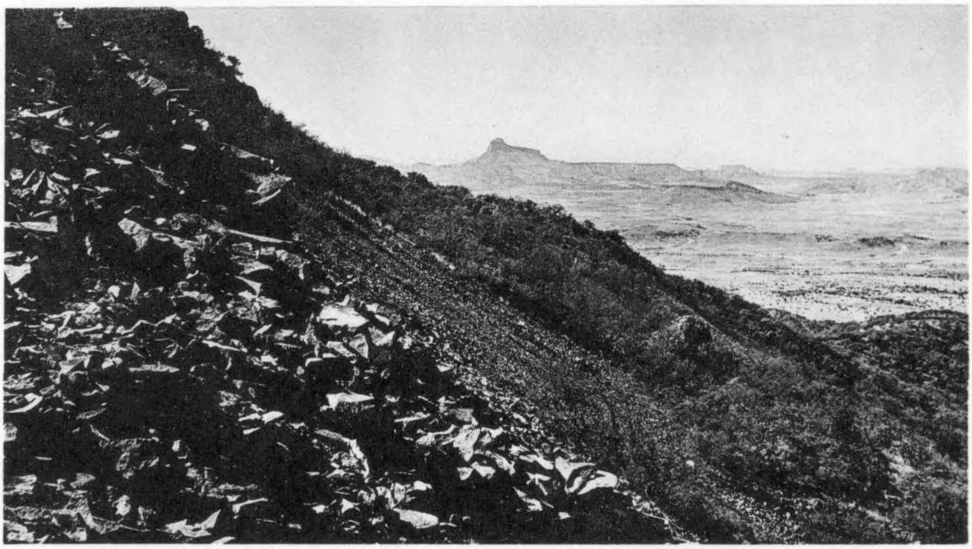


FIGURE 3

STRATIGRAPHY, STRUCTURE, AND TOPOGRAPHY

toward Goat Creek. Goat Creek and its tributaries from the west flow against the dip of the volcanic layers and have carved steep-walled narrow valleys and gorges separated by high, hilly divides. Between the northern edge of this dissected basaltic surface and the steep slope of the southeast escarpment of Goat Mountain is a wide dissected pediment cut on the Duff formation. Its gently sloping surface is indented by numerous gullies and shallow valleys, and there are a few low ridges and isolated hills of more resistant rock, but on the whole there is little relief.

Starting immediately south of Little Cienega Mountain and continuing southward into northern Buck Hill quadrangle, an irregular mountainous trend of dissected ridges and buttelike summits composed of lavas and tuffs forms the drainage divide between Goat and Calamity Creeks. A similar northwest-trending mountainous area divides the drainage between Sheep and Calamity Creeks. These mountainous divides are the western and northern boundaries of Crossen Mesa. From the mouth of Ash Creek northwestward for about 5 miles and then northeastward to the latitude of Mt. Ord, a narrow chain of hills and ridges carved largely on basaltic lavas forms the divide between Calamity and Ash Creeks.

More than 70 per cent of the Cathedral Mountain quadrangle is drained by Calamity Creek and its tributaries, Sheep and Ash creeks; about 25 per cent is drained by Goat Creek. The flat area in the northeast corner (Marfa Plateau) and a part of Mitchell Mesa drain westward into Alamito Creek. Drainage off the steep east-facing Davis Mountains escarpment between Mt. Ord and Elephant Mountain goes via Chalk Valley to Maravillas Creek which flows southeastward across the Del Norte Mountains and the Marathon basin. Extending northwestward from Mt. Ord is an important drainage divide. North of this divide, waters flow northeastward to the Pecos River, and south of it to the Rio Grande. Except for short spring-fed reaches, all streams are intermittent. The longest stretch of permanently flowing water is in Calamity Creek—from the vicinity of Haley Mountain southward to a point west of Elephant Mountain, where the water disappears into the valley fill. Goat Creek carries a trickle of water supplied by seepage springs, and, except during periods of drought, some water is usually present along short stretches in both Sheep and Ash Creeks. Sparse vegetation, a well-developed drainage network with steep gradients, a thin rocky soil mantle, and bare rock surfaces all facilitate rapid run-off. Dry creeks become torrential almost immediately after a heavy rain but diminish within a few hours.

Although the regional dip of the Tertiary volcanic rocks is west and northwest, the master drainage is southward. Most of the tributaries are consequent (or resequent) and form radial or dendritic patterns according to the structure and topography. Ash Creek appears to be a subsequent stream developed almost parallel to the strike of the volcanic layers along the west side of the Mt. Ord structure. Escarpment fronts are scalloped by short obsequent streams. As obsequent streams, Sheep and Torvea creeks have cut far into the escarpment bounding Crossen Mesa. The cross-dip flow of Walnut Draw is due to a graben with increasing displacement toward the southeast. Goat Creek has carved a narrow, steep-walled gorge across southern Crossen Mesa in northern Buck Hill quadrangle, diametrically opposed to the dip of the volcanic rocks. Calamity Creek also flows in a direction opposite to that of the rock inclination, but no canyon or gorge developed where it crosses the eastern escarpment of the Davis Mountains because of the Calamity

PLATE 3.—STRATIGRAPHY, STRUCTURE, AND TOPOGRAPHY

FIGURE 1.—Northwest-facing escarpment of Goat Mountain—(a) Duff tuff, (b) Mitchell Mesa welded tuff, (c) Tascotal tuff, and (d) Rawls basalt

FIGURE 2.—Escarpment bounding Crossen Mesa, northwestward view—(a) Pruett tuff and (b) Crossen trachyte

FIGURE 3.—Looking westward from near the north side of Mt. Ord. Talus deposit on Mt. Ord in left foreground. From south to north in distance are: Cathedral Mountain, Haley Mountain, and the southern part of McIntyre Peak intrusive mass

Creek fault. Maravillas Creek heads on the southern slopes of the Mt. Ord dome and flows southeasterly across the Del Norte Mountains in Monument Spring quadrangle through Doubtful Canyon cut in folded and faulted Cretaceous and Paleozoic strata. Longer canyons in the northern Davis Mountains also oppose the dip of the volcanic layers.

Although several streams appear to be antecedent, they probably originated as consequents on now removed volcanic surfaces and were later superimposed on the buried structure. Great thicknesses of volcanic rock have been stripped from areas where stream courses show least adjustment to structure near the margins of the existing volcanic field. Erosional escarpments on the south and east, 300–1000 feet high, suggest that the volcanic series once extended far to the south and east of the present abrupt terminations. Possibly several hundred feet of lava and tuff covered the Del Norte Mountains and much of the Marathon dome. It does not seem likely, therefore, that Doubtful Canyon, now occupied by eastward-flowing Maravillas Creek, and Del Norte Gap, a wind gap east of Elephant Mountain, were initiated by southwest-flowing consequent streams, as suggested by King (1937, p. 18–19).

Upstream from the escarpments bounding Crossen and North Crossen mesas, only a few narrow, discontinuous, alluviated flats occur along the master stream valleys, but south of the escarpments these streams flow through wide flat alluviated valleys—largest is the Sheep-Calamity Creek valley, between Elephant Mountain and Crossen Mesa. A cutting cycle is now in progress, and the valley fill is trenched by nearly vertical-walled channels 5–20 feet deep.

SUMMARY OF GEOLOGIC HISTORY

Within the limits of the Cathedral Mountain quadrangle, the geologic record begins with deposition of the Word formation during Guadalupe time (Permian). The siltstone, sandstone, and dolomitic limestone of the Word and Capitan formations in the vicinity of Mt. Ord are forereef deposits laid down on the northwest side of the Hovey channel; both formations grade into massive reef deposits northeastward in the Glass Mountains.

The angular unconformity between marine Permian strata and the overlying Bissett conglomerate (Triassic; Dockum) on the northwest slope of the Glass Mountains is evidence of post-Permian, pre-Triassic uplift and erosion. No Jurassic deposits are known in this part of Trans-Pecos Texas, and, presumably, from late Permian to early Cretaceous time this area stood above the sea and from late Triassic on was subjected to erosion. Middle Mesozoic tilting and warping are demonstrated in the Glass Mountains by angular unconformity with overlying Cretaceous and folding of the Bissett conglomerate. If this conglomerate and Permian rocks younger than the Capitan limestone ever were deposited in the area of the Mt. Ord dome, they were removed by post-Permian, pre-Cretaceous erosion. The structurally and topographically high position of the Mt. Ord area in early Cretaceous time probably resulted from the post-Bissett, pre-Cretaceous deformation.

Overlapping of Comanche marine strata shows that the area occupied by Mt. Ord and the northern Del Norte Mountains and most of the Glass Mountains was high in early Cretaceous time; a low ridge probably connected the northern Del Norte and Glass mountains.

There is some evidence that a basin existed in the central part of the Cathedral Mountain quadrangle when the early Cretaceous sea came in. In the Argo Oil Corporation's Mitchell Bros.-State No. 1 well, located on Whirlwind Mesa about 4 miles west of the southwest corner of the Cathedral Mountain quadrangle, only 600 feet of Cretaceous rocks was encountered (DeFord, *in* Goldich and Seward, 1948, p. 37), approximately the same thickness as the Cretaceous section exposed at Mt. Ord. But at Cienega Mountain, about midway between these two points, nearly 1000 feet of Cretaceous sediments is exposed. The Cretaceous in the Argo well was not subdivided, so the formations cannot be compared. The observable Cretaceous record ranges from a conglomeratic sandstone probably equivalent to the Maxon sandstone of the Marathon region (late Trinity or early Fredericksburg) to the Boquillas limestone (middle or upper Eagle Ford). Yet

Comanche Peak limestone and Walnut clay of early Fredericksburg age and Glen Rose limestone of Trinity age outcrop in the Del Norte Mountains in Monument Spring quadrangle along the east side from the southern boundary to within 3 miles of Mt. Ord, and these beds dip west and southwest off the Del Norte Mountains; therefore they probably occur in the subsurface in the southeastern part of the Cathedral Mountain quadrangle.

The Cretaceous period closed with the Laramide uplift and orogeny which produced the ancestral Del Norte-Santiago-Carmen mountains and initiated a broad structural depression to the west of this range; also, the Marathon dome was probably initiated at this time. As the late Eocene age of the basal Tertiary volcanic unit, the Pruett tuff, is now established, the initial Laramide orogeny can be dated as late Cretaceous, pre-upper Eocene; widespread erosion of the Cretaceous beds prior to deposition of the Pruett tuff indicates a late Cretaceous and/or Paleocene or early Eocene age for the deformation.

The long period of post-Cretaceous erosion ended with the explosive volcanic activity which blanketed the surface with volcanic ash. The first showers of ash may have drifted in from sources outside the immediate area, but coarse igneous gravel in conglomerate beds in the upper part of the Pruett formation were probably from near-by sources. Explosive eruption was intermittent, and streams were active on the surface of the ash beds, as shown by the poorly sorted, lenticular stream deposits of tuffaceous sandstone and conglomerate interbedded with the tuff layers. Lenticular beds of fresh-water limestone, largely of organic origin, at different horizons in the Pruett tuff indicate the existence of shallow lakes. Judging from the types of fossil vertebrates and plants found in the basal tuff in the Tierra Vieja and Davis mountains, a warm temperate climate with abundant rainfall prevailed during upper Eocene time in Trans-Pecos Texas.

The intermittent explosive volcanism which supplied the fine pyroclastic material in the Pruett tuff was followed by quieter eruption of acidic lava, the Crossen trachyte. The great lateral extent suggests outpouring from a number of fissures. The Crossen trachyte was then subjected to erosion which produced a hill-and-valley toppgraphy; some valleys were cut completely through it and into the underlying Pruett tuff.

Spreading of lower flows of the Sheep Canyon basalt over the deeply incised surface of the Crossen trachyte initiated a new cycle of volcanic activity which produced basaltic, trachybasaltic, andesitic, and trachyandesitic flows which make up the Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt units of the Buck Hill volcanic succession. Beds of limestone and tuffaceous materials between flows in the lower unit, and deeply weathered and eroded surfaces within and at the tops of the units, are evidence that effusive activity was recurrent over a long period of time.

The Duff formation records the beginning of another long cycle of intermittent explosive volcanism, ending with deposition of the Tascotal formation. Flood-plain and channel deposits of tuffaceous sandstone and conglomerate at several horizons in the Duff and Tascotal formations testify to many quiescent intervals. A thick succession of rhyolitic, trachytic, trachyandesitic, and basaltic flows in the Duff formation (Decie member) in the Alpine (15-min.) quadrangle, tongues of which extend southward into northern Cathedral Mountain quadrangle as thin intercalations in the tuff beds, shows that effusive activity followed periods of explosive eruption and indicates that important sources of the volcanic material in the Duff formation were located near by. That slow downwarping was initiated in late Duff time and continued through Tascotal time in an area embracing Goat and Cathedral mountains is suggested by the apparent thickening of the Tascotal formation and the Rawls basalt and abundant conglomerate in the Tascotal and Duff formations. The Duff formation, Mitchell Mesa welded tuff, and Tascotal formation, a group of dominantly rhyolitic tuffaceous formations in the Cathedral Mountain quadrangle and southward, are possibly Miocene.

After a period of quiescence, during which the Tascotal formation was eroded, extrusive activity was renewed, and basic lavas of the Rawls basalt spread over a large area. The source of the Rawls flows is unknown. The unit is thickest in the southwestern part of Tascotal Mesa quadrangle, and sources which supplied that region may have been in the Bofecillos Mountains. The Cathedral Mountain quadrangle contains only a few erosional remnants. No extrusive igneous rocks younger than the Rawls flows occur, but late Tertiary and Quaternary erosion probably stripped off much of the younger volcanic material and Rawls basalt. Definite dating of the Rawls basalt unit is not now possible but it may be lower Pliocene.

Probably when northwest structural trends (Cordilleran) were developed in this part of Trans-Pecos Texas, after extrusion of the Rawls lava flows and before a late period of syenitic intrusive activity, folding of the volcanic layers resulted in a regional dip of 2°–4° N. and NW. in the southern Davis Mountains. Following or perhaps in part contemporaneous with this regional crustal movement, syenitic magmas intruded the Buck Hill volcanic succession, producing local doming and faulting. It was probably mostly during this period that the Marathon dome was uplifted. Sometime after intrusion of the syenitic magmas, and prior to alluviation of present valleys, large-scale normal faulting developed along lines generally parallel with axes of the earlier folding.

Extrusive vulcanism may easily have been contemporaneous with emplacement of the syenitic intrusive bodies. Several slender conical peaks of intrusive syenite, exposed by deep erosion, may be volcanic necks. Eagle Peak vent, younger than the major normal faulting, is positive evidence of later extrusion. After igneous activity ceased, possibly in late Pliocene, consequent streams developed on a broad volcanic field which extended far to the east and southeast of the present limits of the Buck Hill volcanic series; the Davis Mountains are a relatively small erosional remnant. Since then erosion has been differential.

ECONOMIC GEOLOGY

No ore deposits are known in the Cathedral Mountain quadrangle. Cretaceous limestones in contact with intrusive igneous rocks can be seen only around Cienega Mountain, and little or no contact metamorphism occurs along the volcanic-intrusive contacts. Marmatization of Georgetown and Edwards limestones brought up with the Cienega Mountain syenitic intrusion produced sizable patches of marble and loose granulated limestone relatively free of contact metamorphic silicate minerals.

Agate is plentiful in amygdaloidal zones in all lava units. Highly prized plume and moss varieties are found in the Sheep Canyon and Cottonwood Spring basalts; banded pastel shades occur in the Crossen trachyte, and bloodstone is common in the Potato Hill andesite. Small stringers of milky-blue semi-precious opal occur locally in the Cottonwood Spring and Rawls basalts. Amethyst in small geodes is rare in the basaltic flows. Small euhedral crystals of analcime are abundant in the lowest basalt flow in the Duff formation on the southeast slope of Goat Mountain; clusters of stilbite, showing excellent cruciform twin development, and other zeolites occur at the head of the north branch of Walnut Draw in the Cottonwood Spring basalt.

The large dome beneath Mt. Ord is a possible oil trap, but the igneous cores exposed in many similar structural features in the vicinity suggest the possibility that the dome is underlain at shallow depths by an intrusive igneous body.

The supply of ground water is limited but adequate for ranching requirements. Water is obtained from wells ranging in depth from 25 to 75 feet in alluvium in the valley flats, to 100 to 400 feet in the volcanic rocks. Because of varying permeability of the rocks, a simple and uniform water table does not exist in the volcanic terrane. The water is pumped from wells by windmills into steel or concrete tanks located on high ground and then distributed by pipelines to watering places. Part of the supply is obtained by diverting surface run-off into large earthen tanks; some is furnished by small springs. Spring-fed flow from Calamity Creek is used for small-scale irrigation projects on the Bird and Nevill ranches.

DESCRIPTION of SELECTED MEASURED SECTIONS

Location of the following sections, measured in connection with the detailed geologic mapping of the Cathedral Mountain quadrangle, is shown by appropriate symbol on Plate 1.

Section 1—Maxon sandstone up through lower part of Duff formation, northwest side of Cienega Mountain

	Thickness (Feet)
Duff formation:	
41. Sandstone, conglomerate, and breccia, reddish brown, very hard, cemented with silica; grade sizes range from medium-grained sand to boulders more than 2 feet in diameter; aggregate in conglomerate composed of trachyte and felsitic igneous rocks and large blocks of red baked tuff; lenticular and cross-bedded	38
40. Tuff, red and gray, friable, medium-grained, conglomeratic in places; not well exposed	110
Total:	148
Cottonwood Spring basalt:	
39. Basalt, pinkish gray, weathers dark reddish brown, medium-grained, white speckled owing to abundant small micalike flecks of feldspar; vesicular zones contain much chalcedony; not well exposed; may be tuff layers concealed by debris	286
38. Tuff, gray, medium gray, friable (poorly exposed)	11
Total:	297
Sheep Canyon basalt:	
36. Basalt porphyry, dark brown, medium-grained, abundant large glassy pinkish and yellowish phenocrysts of labradorite	50
35. Basalt, grayish black, fine-grained, nonporphyritic	55
34. Tuff, pink and gray, baked, medium-grained	3
33. Basalt, grayish black, fine-grained, several vesicular zones, calcite abundant in vesicles	116
32. Basalt (?) covered	137
Total:	361
Crossen trachyte:	
31. Trachyte porphyry, dark reddish brown, fine-grained groundmass, abundant stubby phenocrysts of glassy feldspar; well-developed columnar jointing	228
Pruett tuff:	
30. Nearly pure volcanic tuff, gray, fine-grained, massive, contains greenish-gray shaly zones and some calcareous tuff	159
29. Not well exposed in line of section, tuff, gray, friable, lavender shaly zones toward top	85
28. Conglomerate, pink and gray; pebble-size gravel composed of gray, coarse-grained, calcareous tuff; matrix is pink, fine-grained tuff	22
27. Nearly pure volcanic tuff, gray, fine-grained, compact, thin- to thick-bedded, weathers into subrounded to angular fragments	20
26. Tuff, pink and gray, medium-grained, massive, highly calcareous, weathering produces pitted surfaces	5
25. Shale, dark red, fissile	11
24. Volcanic ash, pink to gray, fine-grained, dense to porous, massive, contains flecks of gray tuff; surface pitted by differential erosion; mostly covered	53
23. Conglomerate, mixture of gray, brown, and pink, poorly sorted; gravels range from granule to pebble size and are composed of well-rounded to fine-grained igneous rock and hard silicified tuff. Matrix composed of coarse-grained tuffaceous material; lenticular	12
22. Tuff, light gray, very fine-grained, thin to thick bedded, calcareous, slightly silicified; dense zones grade into porous, medium-grained material, has subconchoidal fracture, grades upward into pink, noncalcareous tuff	64
21. Nearly pure volcanic tuff, pale pink to gray, fine-grained, compact, massive, noncalcareous	32
20. Conglomerate, pinkish gray, weathers brown, poorly sorted, gravel well rounded, granule to cobble size (mostly pebble size), composed of indurated tuff, limestone, and fine-grained igneous rock. Matrix is fine-grained, calcareous tuff; contains lenses of medium- to coarse-grained tuffaceous sandstone; thick bedded	48
19. Tuff, gray, dense, calcareous, compact, alternates with pink, slightly calcareous, less compact tuff, thick bedded	11
18. Volcanic ash, pink, fine-grained, compact, massive, contains small flecks of gray tuff	20

17. Tuff, gray with pink zones, highly calcareous, medium- to coarse-grained, indurated, thick bedded....	35
16. Tuff, light gray to white, noncalcareous, very fine-grained, compact, massive, contains small flecks of mica and tiny particles of a black mineral; forms gentle slope; poorly exposed..........................	85
15. Tuff, light gray, calcareous, fine-grained, dense, subconchoidal fracture, thick bedded, contains flakes of mica..............................	26
14. Tuff, reddish pink, fine- to medium-grained, hard, subconchoidal fracture, thick-bedded, poorly exposed........	42
13. Fresh-water limestone and interbedded calcareous tuff, light gray to greenish gray, medium-grained, crystalline; tuff is fine-grained, very hard, conchoidal fracture, weathers brownish gray with rough pitted surface, thick bedded......................	26
12. Volcanic ash, greenish gray, fine-grained, massive, loose to compact, weathers dirty gray................	4.2
11. Tuffaceous limestone, gray, finely crystalline, slightly silicified, thick-bedded.	3.3
10. Tuff, greenish gray to pink, medium-grained, loose to compact, arenaceous, thick-bedded; weathers into nodular gravel............................	13
9. Tuff, light gray to white, very hard, siliceous, slightly calcareous, massive.	9.5
8. Shale, black, fissile.................	10
Total:............................	798
Georgetown and Edwards limestone (undifferentiated):	
7. Limestone, light gray, metamorphosed, friable, sugary zone alternating with harder recrystallized areas..	125
6. Limestone, dark gray, marmatized; coarse-grained; fossiliferous, large gastropods and rudistids; (location of marble quarry)....................	100
5. Limestone, dirty gray, thick-bedded, medium-grained..................	50
4. Limestone, light gray, dark gray, and mottled, thin to thick bedded; contains thin beds of light yellowish-gray marl; fossiliferous, chert abundant in thin layers along bedding planes, irregular-shaped nodules, and narrow stringers; calcite veins in joints and fractures............................	150
Total:..	425
Maxon (?) sandstone:	
3. Conglomerate, granule to cobble; matrix fine- to coarse-grained quartz sandstone, cemented with silica; gravel composed of well-rounded and polished white vein quartz, black quartzite, and black and varicolored chert; thick-bedded, lenticular......	66
2. Sandstone, light greenish gray, siliceous, well cemented, fine- to medium-grained, thick-bedded; interbeds of light greenish gray; arenaceous shale containing abundant pea-size rounded quartz and chert gravels............	284
1. Sandstone and conglomerate; sandstone is light greenish to dark gray; fine- to coarse-grained quartz sand, coherent, thin to thick bedded, lenticular; conglomerate layers are lenticular, grains rounded, granule to pebble size, composed of quartz and chert, matrix is fine- to coarse-grained sandstone....................	16
Total:..........................	366
Intrusive alkalic syenite (core of Cienega Mountain).	
Total thickness measured:................	2697

Section 2—Upper Crossen trachyte, Sheep Canyon basalt, Potato Bill andesite, and lower Cottonwood Spring basalt in east slope along Walnut Draw

	Thickness (Feet)
Cottonwood Spring basalt:	
6. Basalt, grayish brown, weathers to reddish brown, fine- to medium-grained, nonporphyritic, massive; white flaky grains of feldspar give the rock a speckled appearance; contains flow-breccia and ropy lava, numerous vesicular and amygdaloidal zones.....................	189
Potato Hill andesite:	
5. Decomposed andesite, highly weathered, tuffaceous appearance...............	5
4. Andesite, bluish gray, weathers dark reddish brown, fine-grained, porphyritic, massive; greenish in vesicular areas; abundant amygdules of chalcedony; weathers into thin sheets and slabs; weathered surface grades down into flow-breccia zone...........................	57
Total:................................	62

Sheep Canyon basalt:

3. Highly weathered, tufflike basalt.......	3
2. Basalt porphyry, coal-black, weathers dark reddish brown, fine- to medium-grained; vesicular and amygdaloidal with amygdules of chalcedony and calcite; abundant large, glassy, greenish and yellowish phenocrysts of labradorite; spheroidal weathering well developed in gullies..................................	127
Total:................................	130

Crossen trachyte:

1. Porphyritic trachyte, vesicular, fine-grained, reddish brown and yellow; abundant stubby phenocrysts of anorthoclase (base not exposed).................	26
Total thickness measured:...............	307

Section 3—Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt on west side of Crossen Mesa, north of Torvea Canyon fault

	Thickness (Feet)
Cottonwood Spring basalt:	
13. Basalt flow, grayish black, fine-grained, nonporphyritic.......................	66
12. Tuff, pinkish gray, hard, baked	11
11. Basalt flow, reddish brown, fine- to medium-grained, nonporphyritic, amygdaloidal at top, fillings of chalcedony and calcite.............................	46
10. Basalt flow, reddish brown, fine-grained, nonporphyritic; vesicular zone 15 feet thick at top contains fillings of chalcedony and calcite; flow-breccia 10 feet thick at base...........................	52
Total:................................	175
Potato Hill andesite:	
9. "Tuff," dirty gray, medium-grained, grades downward into weathered andesite..................................	31
8. Porphyritic andesite, reddish brown, weathers greenish locally, fine-grained; contains abundant phenocrysts of yellowish plagioclase phenocrysts, some up to 1 inch long and half an inch wide; vesicular and amygdaloidal zone at top grades downward into massive lava; abundant chalcedony and calcite fillings..........	82
Total:..................................	113
Sheep Canyon basalt:	
7. Tuff, dirty gray; contains fragments of basalt; grades downward into weathered basalt................................	23
6. Porphyritic basalt, dark greenish black, fine- to medium-grained; glassy plagioclase phenocrysts abundant locally.	31
5; Porphyritic basalt, coal-black, weathers reddish brown, medium-grained, large glassy phenocrysts of plagioclase feldspar abundant; amygdaloidal top with chalcedony and calcite fillings................	62
4. Tuff, light gray, medium-grained, compact...............................	5
3. Tuff, light gray, medium-grained, compact................................	5
2. Porphyritic basalt, coal-black, weathers reddish brown, fine- to medium-grained; abundant glassy plagioclase phenocrysts; vesicular and amygdaloidal zones contain much chalcedony and calcite........	39
1. Tuff, yellowish gray, medium-grained (poorly exposed)........................	18
Total:..................................	183
Crossen trachyte.	
Total, thickness measured:................	440

Section 4—Sheep Canyon basalt, Potato Bill andesite, and Cottonwood Spring basalt, on spur between Calamity Creek and Sheep Creek

	Thickness (Feet)
Cottonwood Spring basalt:	
12. Basalt, dark grayish brown, fine-grained, nonporphyritic, white speckled owing to abundant mica-like flakes of feldspar, vesicular at top.........................	38
Potato Hill andesite:	
11. Tuff, gray and pinkish gray, fine- to medium-grained, hard, baked, breaks with conchoidal fracture.............	14
10. Porphyritic andesite, bluish gray, weathers reddish brown; fine-grained groundmass, many stubby, glassy, plagioclase phenocrysts; vesicular top contains much chalcedony, some opal, a few quartz geodes; weathers into thin sheet and slabs; coarse flow-breccia zone at base...............................	79
Total:..................................	93
Sheep Canyon basalt:	
9. Basalt, fine- to medium-grained, with abundant large glassy, greenish, yellowish, and clear phenocrysts of labradorite (up to 2 inches long), coal-black on fresh break, weathers dull reddish brown.....	16
8. Tuff breccia, bluish gray, silicified, has conchoidal fracture, contains angular fragments of feldspar and quartz in fine-grained groundmass................	9

7. Basalt, fine- to medium-grained, ppr-phyritic, contains vesicular zones with much agate and jasper fillings, coal-black; weathers dull reddish brown and greenish gray	25
6. Limestone, gray, cherty, fossiliferous	3
S. Basalt, fine-grained, coal-black, weathers dull reddish brown and greenish gray; contains "stalactitic" ortubularrods 3/16 to 3/4 inch in diameter with cores composed of yellowish and reddish moss agate and an outside coating of dull chalcedony	26
4. Tuff, bluish gray, friable, with baked zones	5
3. Basalt, fine-grained, porphyritic with large glassy phenocrysts of labradorite; vesicular zone in upper 15 feet contains flow-breccia made up of large angular blocks of cindery and dense basalt; vesicular zone weathers a distinctive greenish color, small vesicules are filled with chalcedony and calcite (are also large geodal masses of calcite up to 6 inches in diameter), abundant banded and moss agate and jasper, veins of calcite and jasper cut the vesiculated zone; dense material is coal-black on fresh break, weathers reddish brown	70
2. Tuff breccia, reddish brown, hard, baked, has conchoidal fracture	1-2
1. Basalt, fine- to medium-grained, porphyritic with large glassy phenocrysts of labradorite, coal-black, weathers dull reddish brown; cores from spheroidal weathered masses abundant over the surface	97
Total:	250
Pruett tuff.	
Total thickness measured:	381

Section 5—Pruett tuff and Sheep Canyon basalt, westward from large earthen tank in Chalk Valley up east-facing escarpment at north end of North Crossen Mesa

	Thickness (Feet)
Sheep Canyon basalt:	
12. Flow-breccia	20
11. Porphyritic basalt, black, weathers reddish brown, fine- to medium-grained, contains scattered glassy plagioclase phenocrysts	37
10. Tuff, gray, hard, fine-grained	20
9. Basalt porphyry, black, weathers reddish brown, large glassy plagioclase phenocrysts abundant; vesicular zone 15 feet thick near top	65
8. Flow-breccia	62
7. Basalt porphyry, black, weathers reddish brown, medium-grained, plagioclase phenocrysts abundant; upper 10 feet is vesicular with fillings of chalcedony and calcite	77
Total:	281
Pruett tuff:	
6. Limestone, gray, siliceous	10
5. Tuff, light greenish gray, medium-grained, thick-bedded	103
4. Tuff, yellowish gray, sandy, medium-grained, friable	5
3. Tuff, light greenish gray, fine- to medium-grained, thick- to massive-bedded, compact	36
2. Tuff, yellowish gray, fine-grained, alternating hard and soft layers	21
1. Tuff, pink and gray (not well exposed)	165
Total:	340
Alluvium.	
Total thickness measured:	621

Section 6—Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt, southeast of Anderson ranch house, northward in slope at north edge of North Crossen Mesa

	Thickness (Feet)
Cottonwood Spring basalt:	
12. Basalt, grayish black) fine-grained, nonporphyritic; prominent flow-breccia about 10 feet thick in lower part	25
11. Basalt, grayish black, fine-grained, nonporphyritic, 15-foot vesicular zone at top, contains fillings of chalcedony and calcite	35
10. Basalt, grayish black, fine-grained, nonporphyritic, 5-foot vesicular zone at top	58
9. Tuff, gray, lenticular; poorly exposed	5
8. Basalt, grayish black, fine-grained, nonporphyritic; contains amygdaloidal and vesicular zones with chalcedony and calcite fillings	61
Total:	184
Potato Hill andesite:	
7. Weathered andesite	2
6. Porphyritic andesite, greenish gray, weathers dull brown, fine-grained, contains scattered glassy plagioclase phenocrysts	51
Total:	53
Sheep Canyon basalt:	
5. Basalt porphyry, black, weathers reddish	

brown, medium-grained, large glassy plagioclase phenocrysts are abundant... 26
4. Tuff, gray; poorly exposed............ 5
3. Basalt porphyry, black, weathers reddish brown, fine- to medium-grained; upper 15 feet is composed of coarse flow-breccia.............................. 82
2. Tuff, gray.......................... 5
1. Porphyritic basalt, coal-black, weathers reddish brown, some large plagioclase phenocrysts............................. 41
Total:.................................. 159

Crossen trachyte.
Total thickness measured................ 396

Section 7—Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt, near intersection of Calamity Creek fault and State highway No. 118, east of highway—up slope to northeast

Thickness (Feet)

Cottonwood Spring basalt:
6. Basalt, grayish black, fine-grained, nonporphyritic; vesicular and amygdaloidal zones contain appreciable fillings of chalcedony and calcite; probably 2 or 3 flows.................................. 102

Potato Hill andesite:
5. Tuff or highly decomposed andesite, gray, contains small fragments of lava.. 10
4. Andesite, grayish brown, fine-grained; contains scattered small pink plagioclase phenocrysts........................ 72
Total:.............................. 82

Sheep Canyon basalt:
3. Highly weathered and decomposed basalt, gray, contains small weathered fragments of basalt, tuffaceous in appearance. 8
2. Basalt porphyry, black, weathers reddish brown, medium-grained, large glassy plagioclase phenocrysts are abundant... 57
1. Tuff, gray, medium-grained (not well exposed).............................. 25
Total:................................ 90

Crossen trachyte.
Total thickness measured:............. 274

Section 8—Sheep Canyon basalt, Potato Sill andesite, and Cottonwood Spring basalt, in slope east of Ash Creek, about 1 mile northeast of Anderson ranch house

Thickness (Feet)

Cottonwood Spring basalt:
5. Basalt, grayish black, fine-grained, nonporphyritic; 2 vesicular zones; probably 3 flows................................ 101

Potato Hill andesite:
4. Andesite, greenish gray, weathers dull brown; contains a few small glassy plagioclase phenocrysts......................... 41

Sheep Canyon basalt:
3. Tuff or highly decomposed basalt, gray. 5
2. Basalt porphyry, black, weathers reddish brown, fine- to medium-grained, abundant plagioclase phenocrysts........... 87
1. Tuff, gray (poorly exposed)........... 40
Total:............................... 132

Crossen trachyte.
Total thickness measured:............... 274

Section 9—Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt, in slope eastward from Calamity Creek, east of Bird ranch house

Thickness (Feet)

Cottonwood Spring basalt:
6. Basalt, grayish black, weathers grayish brown, fine-grained, nonporphyritic; vesicular zones contain fillings of chalcedony and calcite..................... 103

Potato Hill andesite:
5. Andesite, greenish gray, weathers dull brown; slightly plagioclase phenocrysts. 41

Sheep Canyon basalt:
4. Tuff or highly decomposed basalt, gray. 7
3. Basalt porphyry, greenish black, weathers reddish brown; abundant plagioclase phenocrysts; vesicular and amygdaloidal zones contain chalcedony and calcite.......................... 36
2. Tuff, gray (poorly exposed)........... 62
1. Porphyritic basalt, black, weathers reddish brown, medium-grained, contains scattered plagioclase phenocrysts....... 42
Total:............................... 147

Crossen trachyte.
Total thickness measured:............. 291

Section 10—Duff formation, Mitchell Mesa welded tuff, Tascotal formation, and Rawls basalt, in southeast slope and escarpment of Goat Mountain

Thickness (Feet)

Rawls basalt:
21. Basalt, dark brown, fine-grained, contains large areas of massive, coarse flow-breccia; black chalcedony is abundant as a botryoidal coating and cavity filling; numerous geodes lined with quartz crystals.............................. 210

Tascotal formation:
20. Tuff, gray and yellowish gray, medium-

to coarse-grained; contains sandstone and conglomerate lenses; poorly exposed	190
Mitchell Mesa welded tuff.	
19. "Rhyolite" porphyry (welded tuff), gray to pink groundmass contains abundant phenocrysts of quartz and anorthoclase, dense to vesicular; well-developed vertical jointing; unconsolidated zone at base	90
Duff formation:	
18. Tuff, light gray, ashy, massive	240
17. Sandstone and conglomerate, brown and reddish brown, poorly sorted, cross-bedded, lenticular, shows scour-and-fill relations; sandstone is tuffaceous, fine- to coarse-grained; conglomerate composed of well-rounded igneous rock gravels ranging from granule to cobble in size, cemented with tuffaceous sandstone, thin layers of tuff are interbedded	90
16 Tuff, light gray, fine- to medium-grained, compact, massive	260
15. Basalt, grayish brown, vesicular and cavernous; calcite and zeolites abundant	40
14. Tuff, light gray, ashy; contains thin arenaceous lenses	340
13. Tuff, light gray to white, nearly pure volcanic ash 1–8 inches wide—two sets trending at right angles to each other; contains several beds of "mud pellet" conglomerate	100
12 Basalt, dark brown, highly weathered; contains analcime, natrolite, and calcite	10
11. Tuff, gray, poorly exposed	90
10. Sandstone and conglomerate, brown, lenticular, cross-bedded	15
9. Tuff, gray	10
8. Sandstone and conglomerate, brown, lenticular, cross-bedded	5
7. Tuff, pinkish gray, friable	15
6. Conglomerate, dark red, hard; well cemented, poorly sorted, well-rounded grains of igneous rock ranging from granule to cobble in size	3
5. Tuff, gray, poorly exposed	20
4. Sandstone and fine-grained tuff, indurated	6
3 Tuff, gray, friable, massive	70
2 Sandstone and conglomerate, reddish brown, mostly conglomerate with matrix of coarse-grained sandstone, igneous rock pebbles and cobbles well rounded	25
1. Tuff, gray, medium-grained, friable, massive	60
Total:	1399
Cottonwood Spring basalt.	
Total thickness measured:	1889

Section 11—Sheep Canyon basalt, Potato Hill andesite, and Cottonwood Spring basalt, from lower slope of Mt. Ord westward across Ash Creek and State highway No. 118

	Thickness (Feet)
Cottonwood Spring basalt:	
11. Basalt, dark gray, fine-grained, nonporphyritic	15
Potato Hill andesite:	
10. Tuff or highly decomposed lava, dull red, medium- to coarse-grained, hard, baked toward top	15
9. Andesite flow, very fine-grained, reddish gray, weathers dark brown, nonporphyritic; contains vesicular zones, thin flow-breccia at base	55
Total:	70
Sheep Canyon basalt:	
8. Contact between Sheep Canyon and Potato Hill covered; weathered basalt (?)	3
7. Basalt, fine-grained, phenocrysts scarce, coal-black, weathers dull reddish brown.	12
6. Tuff, pinkish gray; poorly exposed	20
5. Basalt, fine- to medium-grained, contains glassy yellow and greenish phenocrysts of labradorite up to 3 inches long (most larger than ½ inch and less than 1½ inches), and large glassy, jet black phenocrysts of hypersthene (1–2 inches long), coal-black, weathers dull reddish brown; about 25 feet above the base is a vesicular zone containing appreciable calcite filling	83
4. Tuff breccia, gray, silicified; a very distinctive bed in the Sheep Canyon, only 5–10 feet thick and caps less-indurated rhyolitic tuff in most places	28
3. Basalt, fine-grained, coal-black, weathers dull reddish brown (greenish gray in gullies), contains scattered phenocrysts of labradorite; cindery vesicular zones with abundant yellowish brown jasper	149
2. Covered by alluvium along Ash Creek	132
1. Basalt, fine-grained, nonporphyritic, coal-black on fresh break, weathers dull reddish brown, platy jointing	27
Total:	454
Crossen trachyte.	
Total thickness measured:	539

Section 12—Pruett tuff and Crossen trathyte, in east-facing escarpment of Mt. Ord

	Thickness (Feet)
Crossen trachyte:	
6. Porphyritic trachyte, reddish-brown groundmass, abundant stubby phenocrysts of anorthoclase; vesicular zone near top; well-developed columnar jointing	265
Pruett tuff:	
5. Tuff, gray; covered by talus from overlying trachyte	210
4. Limestone and calcareous tuff, gray, siliceous	6
3. Tuff, red and gray; contains thin freshwater limestone interbeds; poorly exposed.	88
2. Tuff, gray, calcareous, sandy at base	6
1. Tuff, gray; poorly exposed	170
Total:	480
Buda limestone.	
Total thickness measured:	745

Section 13—Pruett tuff, at locality where fossil vertebrates occur on west side of Chalk Valley

	Thickness (Feet)
6. Sandstone and conglomerate, light-gray to greenish-gray and pink, fine- to medium-grained sandstone, thin- to thick-bedded, alternating with lenticular beds of breccia conglomerate; pebbles in conglomerate are indurated tuff and fine-grained igneous rock, in medium- to coarse-grained tuffaceous matrix; conglomerate contains fragments and complete mammal bones (titanothere) and numerous high-spire gastropods	50
5. Tuff, light gray, argillaceous, fine-grained, soft, thick-bedded	15
4. Tuff or volcanic ash, light gray, fine-grained, sandy, compact, massive	35
3. Tuff, gray, fine-grained, contains thin layers of loose shaly tuff	23
2. Tuff (volcanic ash), light gray, fine- to medium-grained, massive compact	10
1. Volcanic tuff, purplish gray, fine-grained, loose to compact, not well exposed	188
Total thickness measured:	331

Section 14—Pruett tuff, in Mt. Ord basin

	Thickness (Feet)
11. Covered in line of section, tuff, gray	252
10. Limestone, gray, granular, contains stringers of siliceous material	8
9. Tuff, yellowish gray, soft, marly, thick-bedded	30
8. Limestone, gray, granular, massive	4
7. Tuff, yellowish gray, calcareous, soft, marly in appearance, weathers into irregular-shaped nodules, massive	15
6. Tuff, yellowish gray (purplish in places), friable, medium-grained, thin- to thick-bedded, contains hard dense layers that stand up in ledges	15
5. Tuff, gray, medium-grained, friable, thick-bedded, grades upward into hard, reddish, fine-grained tuff at top	30
4. Limestone, gray, crystalline	3
3. Tuff, light gray, friable, thick-bedded	37
2. Limestone, gray, coarse-grained, with stringers and irregular areas of quartz and chalcedony	3
1. Tuff, gray, weathers yellow, brown, thick-bedded, arenaceous zones, cut by numerous narrow clastic dikes of fine-grained tuffaceous material	80
Total thickness measured:	477

REFERENCES CITED

Adams, J. E., Newell, W. D., Wills, N. H., Frenzel, H. N., and Rhodes, M. L., 1949, The Permian rocks of the Trans-Pecos region: West Texas Geol. Soc. Guide Book, Field Trip No. 4, Midland, Texas.

Adkins, W. S., 1927, Geology and mineral resources of the Fort Stockton quadrangle: Univ. Texas Bull. 2738, 166 p.

Albritton, C. C., Jr., and Bryan, Kirk, 1939, Quaternary stratigraphy in the Davis Mountains, Trans-Pecos Texas: Geol. Soc. America Bull. 50, p. 1423–1474.

Berry, E. W., 1919, An Eocene flora from Trans-Pecos Texas: U. S. Geol. Survey Prof. Paper 125-A, p. 1–9.

Eifler, G. K., Jr., 1943, Geology of the Santiago Peak quadrangle, Texas: Geol. Soc. America, Bull. 54, p. 1613–1644.

—— 1951, Geology of the Barrilla Mountains, Texas: Geol. Soc. America, Bull. 62, p. 339–354. Reprinted as Univ. Texas Bur. Econ. Geology, Rept. Inv. 8.

Erickson, R. L., 1953, Stratigraphy and petrology of the Tascotal Mesa quadrangle, Texas: Geol. Soc. America, Bull. 64, p. 1353–1386. Reprinted as Univ. Texas Bur. Econ. Geology, Rept. Inv. 18.

Fenner, C. N., 1948, Incandescent tuff flows in southern Peru: Geol. Soc. America Bull. 59, p. 879–893.

Gilbert, C. M., 1938, Welded tuff in eastern California: Geol. Soc. America Bull. 49, p. 1829–1862.

Goldich, S. S., and Elms, M. A., 1949, Stratigraphy and petrology of the Buck Hill quadrangle, Texas: Geol. Soc. America Bull. 60, p. 1133–1182. Reprinted as Univ. Texas Bur. Econ. Geoloy, Rept. Inv. 6.

Goldich, S. S. and Seward, C. L., 1948, Green Valley-Paradise Valley field trip: West Texas Geol. Soc. Guide Book, p. 10–36, Midland, Texas.

Graves, R. W., 1949, Geology of the Hood Spring quadrangle, Texas: Univ. Texas Bur. Econ. Geology, Rept. Inv. 21, 1954.

Henderson, Junius, 1935, Fossil nonmarine Mollusca of North America: Geol. Soc. America Spec. Paper 3, 313 p.

Huffington, R. M., 1943, Geology of the northern Quitman Mountains, Trans-Pecos Texas: Geol. Soc. America, Bull. 54, p, 987–1046.

King, P. B., 1930, The geology of the Glass Mountains, Texas, Part 1, Descriptive geology: Univ. Texas Bull. 3038, 167 p.

—— 1935, Outline of structural development of Trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull. 19, p. 221–261.

—— 1937, Geology of the Marathon region, Texas: U. S. Geol. Survey Prof. Paper 187, 148 p.

—— 1942, Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull. 26, p. 535–763.

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

Lonsdale, J. T., 1940, Igneous rocks of the Terlingua-Solitario region, Texas: Geol. Soc. America, Bull. 51, p. 1539–1626.

Lord, E. C. E., 1900, Report on igneous rocks from the vicinity of San Carlos and Chispa, Texas: U. S. Geol. Survey Bull. 164, p. 88–95.

Mansfield, G. R., and Ross. C. S., 1935, Welded rhyolitic tuffs in southeastern Idaho: Am. Geophys. Union Trans., p. 308–321.

Marshall, P., 1935, Acid rocks of the Taupo-Rotorua volcanic district: Royal Soc. of New Zealand, Trans. and Proc., v. 64, p. 323–336.

Moon, C. G., 1953, Geology of the Agua Fria quadrangle, Brewster County, Texas: Geol. Soc. America, Bull. 64, p. 151–196. Reprinted as Univ. Texas Bur, Econ. Geology, Rept. Inv. 15.

Osann, C. A., 1893, Report on the rocks of Trans-Pecos Texas: Texas Geol. Survey 4th Ann. Rept. 1892, p. 123–137.

—— 1896, Beiträge zur Geologie und Petrographie der Apache (Davis) Mts., West Texas: Tschermak's mineralogische und petrographische Mitteillungen, N. F., B. 15, p. 394–456.

Shrock, R. R., 1948, Sequence in layered rocks; N. Y. McGraw-Hill Book Co., 507 p.

Stovall, J. W., 1948, Chadron vertebrate fossils from below the Rim Rock of Presidio County, Texas: Am. Jour. Sci., v. 246, p. 78–95.

Udden, J. A., 1917, Notes on the geology of the Glass Mountains: Univ. Texas Bull. 1753, p. 3–59.

Vaughan, T. W., 1900, Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, p. 76–81.

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