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GEOLOGY OF EAGLE MOUNTAINS AND VICINITY, HUDSPETH COUNTY, TEXAS

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INTRODUCTION

Eagle Mountains and vicinity include three physiographically distinct but stratigraphically and structurally related sub-units: a central, topographically high mass, Eagle Mountains; a much lower northwestward extension, Devil Ridge; and a south-southeastward extension, Indio Mountains. These highlands, trending generally northwest to north-northwest, surrounded by "bolsons" or intermontane basins partly filled with alluvium, are an extension into southeastern Hudspeth County of the eastern part of a long, narrow, mountainous, structural belt that begins some 150 miles southeast near Ojinaga, Chihuahua, Mexico. The summit of Eagle Peak, 17 miles southwest of Van Horn, Culberson County, and 24 miles southeast of Sierra Blanca, Hudspeth County, and 7,496 feet above sea level, is the highest point in Hudspeth County. Lowest point in the map area, the southeastern corner along the Rio Grande, is 3,150 feet above sea level; the maximum difference in elevation is about 4,350 feet.

In the highlands, well-exposed rocks ranging in age from Precambrian to Recent include about 5,000 feet of metamorphosed Precambrian sedimentary rocks, at least 1,000 feet of Permian limestone, and about 7,000 feet of marine Cretaceous strata, much of which is covered by an early Tertiary volcanic rock sequence of flow breccia and fine-grained flow and pyroclastic rocks. Small intrusive bodies, mainly sills and dikes, crop out throughout the area; the highest part of the Eagles is a small, roughly semicircular stock. The range is flanked by well-defined alluvial fans and terraces.

The stratigraphy of the Cretaceous rocks was controlled by a fluctuating shoreline during the general advance of the Cretaceous sea north and east from the Chihuahua trough onto the Diablo Platform and the continental margin; structurally, the spatial relationships of the Cretaceous rocks were controlled by their location (1) on the southwest flank of the Van Horn uplift, (2) near the northwest end of the Laramide Chihuahua tectonic belt, and (3) near the eastern margin of the Basin-and-Range province.

The map area is in the Mexican Highlands section of the Basin-and-Range province; the highlands of the Eagle Mountains and vicinity are horsts flanked by intermontane basins or grabens, all of which were created by mid-to-late Tertiary block faulting that followed the volcanic activity. This deformation was superimposed on earlier Laramide folds, thrust faults, and strike-slip faults characteristic of the Chihuahua tectonic belt.

The thickness of the alluvial fill in the fault-created intermontane basins is not certainly known, but several deep water wells are believed to be bottomed in the alluvium; at the head of Green River, the fill is at least 1,100 feet thick; at Hot Wells, at least 1,000 feet thick; and near Red Light windmills, at least 660 feet thick. In the closed basins, the drainage systems are responding to a rising base level, whereas the open drainage systems are operating under a régime in which base level is dropping. Basin integration is advanced.

Previous work is summed up as follows: Baker (1927) recognized thrust faults in the area and described in a general way the stratigraphy, structure, and igneous geology of a large region which included the Eagle Mountains and vicinity. Smith (1940) mapped a large part of the Devil Ridge area, and Gillerman (1953), investigating the fluorspar deposits, mapped the central part of the Eagle Mountains. Flawn (1953) mapped Precambrian and adjacent rocks in the Eagle Mountains. A large part of the Indio Mountains was mapped by graduate students of The University of Texas: G. B. Adams, E. Allday, J. N. Smith, and D. L. Bostwick in 1952 and D. R. Frantzen and P. Braithwaite in 1957. The valuable assistance of R. K. DeFord, W. R. Muehlberger, J. W. Macon, and the late J. T. Lonsdale is gratefully acknowledged. K. P. Young identified the Cretaceous fossils, J. A. Wilson identified the vertebrate fossils, and Garner Wilde, Humble Oil & Refining Company, and C. A. Ross, Illinois State Geological Survey, identified the fusulinids. J. C. Yeager, W. R. Cleaves, S. C. Hamilton, Jr., and D. L Kirksey were enthusiastic and capable field assistants. This map and text are an abridgment of a doctoral dissertation (Underwood, 1962).

GEOLOGIC FORMATIONS

Rocks exposed in the Eagle Mountains and vicinity range in age from Precambrian to Recent. Igneous intrusive and extrusive rocks as well as basin fill, terrace gravel, alluvium, and windblown sand constitute the rocks of Tertiary and Quaternary age. Pre-Cenozoic rocks exposed in the map area are of Precambrian, Permian, and Cretaceous age, but the subsurface pre-Cenozoic stratigraphic record is probably more nearly complete.

PRECAMBRIAN ROCKS

CARRIZO MOUNTAIN FORMATION

The Carrizo Mountain Formation includes the oldest exposed rock in the region and is best exposed about 5 miles northeast of the Eagle Mountains in the Carrizo Mountains. It is also exposed along the western margin of the Wylie Mountains about 16 miles east, in the northeastern and northwestern parts of the Van Horn Mountains about 8 miles east-southeast, and on the northeast flank of the Eagle Mountains (K-14). The small exposure in the Eagle Mountains is the southwesternmost exposure of basement rocks on the Van Horn uplift in the Eagle Mountains.

According to Flawn (1953, pp. 45-50), the Carrizo Mountain Formation is a body of low-grade metamorphic rocks about 5,000 feet thick that includes meta-arkose, metaquartzite, schist, phyllite, and limestone. Retrogressive cataclastic metamorphism superimposed on an earlier progressive metamorphism failed to obliterate many of the sedimentary structures. Foliation is commonly parallel to bedding. Strike averages N. 70° E. and dip, 60° to 65° SE. Flawn mapped five unnamed rock units in the Carrizo Mountain Formation exposed in the Eagle Mountains; they are, beginning with the lowest and oldest, described below.

Feldspathic metaquartzite (p-€Cq).—Feldspathic metaquartzite is the major Precambrian rock unit; it is about 3,200 to 3,400 feet thick and constitutes 60 percent of the exposed Precambrian section. This fine-grained, hard, brown metaquartzite with interbedded phyllite layers forms rough, blocky ledges. It is commonly micaceous (sericitic) and has a striped appearance owing to dark thin bands of a black metallic mineral. The texture ranges from granoblastic to lepidoblastic. Bedding is well preserved; cross-bedding is common.

Meta-arkose (p-€Cma). — A 50-foot (maximum) wedge of fine-grained, massive, brown, biotite-rich meta-arkose comformably overlies the metaquartzite. Interbedded with the meta-arkose are thin beds of quartzite and phyllite and thin layers of amphibolite. An amphibolite sill separates the meta-arkose from the overlying metamorphic unit. An equigranular texture has been partially developed through recrystallization; a relict clastic texture is still visible.

Mixed unit 1 (p-€m_1).—Mixed unit 1 consists of alternating 2- to 5-foot beds of fine-grained, brown metaquartzite, brown-to-gray phyllite, and fine-grained mica schist. The fine-grained schistose metaquartzite has compound texture, for superimposed by recrystallization on the original clastic texture are granoblastic and lepidoblastic textures. Incipient mylonization has resulted in a mortar texture.

The phyllite is a microlayered rock; the layers are defined by grain size and micaceous minerals. This rock of smeared, partly bleached biotite, chlorite, and quartz has a relict porphyroblastic texture with a superimposed retrograde texture. Elongate quartz augen of relatively coarse grain contain helicitic garnets almost completely altered to chlorite.

This mixed unit is incompetent and chevron folds are common, especially in the phyllitic units along the Rhyolite fault. Because of the folding, thickness is difficult to estimate, but 600 feet is a reasonable minimum. The unit is underlain by the amphibolite sill cited earlier and unconformably overlain by the Hueco Limestone.

Mixed unit 2 (p-€Cm_2).—Dark slate, dark phyllite, and black limestone compose mixed unit 2, which is separated from the unit just described by the Rhyolite fault. Colluvium from the massive, overlying Hueco Limestone covers much of this unit.

The aphanitic, gray-to-black limestone with siliceous laminae occurs with the dark slate and phyllite in beds less than 5 feet thick. The limestone is actually 55 to 75 percent carbonate and 10 to 30 percent quartz in a fine-grained matrix. Between the grains and perhaps comprising as much as 5 percent of the rock, there is a fine-grained black, opaque, sooty material, probably carbonaceous. Partly bleached, oriented biotite flakes comprise 1 to 10 percent of the rock. Microlayers are defined by quartz or carbon content of the layers or by both.

Amphibolite (p-€C_a).—Two major amphibolite sill-like masses and a number of smaller amphibolite bodies occur in the Carrizo Mountain Formation of the Eagle Mountains; only the two larger masses were mapped. The largest of the two is 150 feet thick and characteristically massive, although schistose outcrops are present. The amphibolite, non-oriented or poorly oriented hornblende and biotite in an oligoclase-andesine matrix, is green black with grain size averaging 0.01 to 1 mm with local coarsenings. Small prisms of hornblende are visible to the naked eye.

The rock has a compound texture, and the original hypidiomorphic granular texture has not been obliterated by metamorphism, which partly reduced the large grains of hornblende to masses of small needles and partly recrystallized the plagioclase. Progressive and retrograde metamorphism cannot be distinguished; the amphibolite probably underwent only the later cataclastic metamorphism.

Quartz-tourmaline veins.—Broken and crushed lenses and veins of white quartz containing black tourmaline and ilmenite occur throughout the area. Their shattered nature may be due to pre- or synmetamorphic hydrothermal activity.

PERMIAN ROCKS

HUECO LIMESTONE

Erosion of Tertiary and Cretaceous rocks has exposed at least a thousand feet of Permian rocks in relatively small outcrops along the north flank of the Eagles: specifically, (1) in a small outcrop (E-8) northwest of Partition tank; (2) east of Eagle Spring in low, rounded hills, which structurally are part of a faulted and eroded anticline; (3) in the lower half of Espy Ridge; (4) in the scarp that borders the Precambrian outcrop south and southeast; and (5) in the low, rounded hills south of the Rhyolite fault. The Hueco Limestone is subdivided into an upper, dominantly carbonate member (Ph) and a basal terrigenous member, the Powwow Conglomerate (Php).

About 1,060 feet of the upper limestone member (Ph) was measured at MS 14 (K.9–14.8); the base is not exposed and the section crosses a gently dipping thrust fault. Gillerman (1953, p. 14) measured a little more than 1,000 feet of Permian rock in the low hills northeast of Eagle Spring and in the area south of the Rhyolite fault. The Powwow Conglomerate, not everywhere present at the base of the Hueco, has a minimum thickness of nearly 170 feet at the easternmost Permian exposure (MS 7), where it is faulted at the base and covered at the top.

An angular unconformity separates Permian rocks from the underlying Precambrian rocks; the nature of the upper contact, however, is not everywhere certain. The Yucca Formation rests disconformably on the Hueco at MS 14 and near Eagle Spring, but along the northeast face of Espy Ridge, limestone of the Bluff Formation either rests disconformably on the Hueco or is faulted against it so that the Yucca has been eliminated. The pre-Cretaceous surface may have been so uneven that the Yucca was deposited only in topographically low areas that flanked hills of Permian rock.

The Hueco is a medium gray to medium dark gray, thin-bedded, compact, very finely crystalline limestone, which has a fetid odor when fractured. There are irregular patches and nodules of brown-weathering chert in the upper half; veins of calcite are common in the lower half.

The basal Powwow Conglomerate (Php) is horizontally and vertically heterogeneous. At MS 7 it is at least 168 feet thick and consists of light to dark gray, generally finely crystalline, compact limestone; light gray, fine- to coarse-grained quartz sandstone; and light gray calcirudite and calcarenite. Eight feet of pale red siltstone near the base contains subrounded to subangular calcareous nodules. The Powwow at MS 7 is probably correlative with the upper part of the Powwow of the Van Horn, Carrizo, and Wylie Mountains. The lower part of the Powwow, composed of poorly consolidated and poorly sorted angular fragments of underlying Precambrian rock ranging up to boulder size, is exposed only in small gullies (K.6–13.7) southwest of Rincon tank and in the upper reaches (K.2–13.8) of the gully that drains north-northeast into Corner tank. In places the Powwow is missing; for example, in the hillside (K.3–14.5) south of the old mines in the Precambrian area, where the Hueco rests directly on Precambrian rock.

About 1,000 feet southeast of MS 7,

low on the northeast flank of the Permian outcrop, there are beds of limestone and chert-pebble conglomerate, which resemble parts of the Yearwood Formation of the Van Horn Mountains (Twiss, 1959a, b). These strata, however, may be part of the Powwow Conglomerate stratigraphically lower than that measured at MS 7.

Fusulinids collected from the base of the northeast flank (H.4–13.0) of the low Permian hills northeast of Eagle Spring are not silicified. C. A. Ross identified them as *Schwagerina laxissima* Dunbar and Skinner and *Pseudoschwagerina uddeni* (Beede and Kniker) and correlated the fusulinid-bearing beds with the *lower* part of the Hueco Limestone of the Hueco Mountains. Other fusulinids were collected from the low, round Permian hills south of the Rhyolite fault from beds that are skeptically correlated with non-fusulinid-bearing beds approximately 885 feet above the base of MS 14. Garner Wilde reported that the fusulinids appear to belong to the upper part of the Wolfcampian and that most of them are intermediate between *Triticites* and *Pseudoschwagerina* and closely related to forms such as *Pseudofusulina? moranensis* Thompson and *Pseudoschwagerina convexa* Thompson. *Triticites* s.s. was also tentatively identified in the samples. The age of the Permian limestone of the Eagle Mountains is thus almost certainly Wolfcamp, and the formation is correlative, totally or in part, with the Hueco Limestone of the Hueco Mountains. The age of the Powwow is inferred. Its stratigraphic position and the four species of ostracodes and the one species of foraminifera reported from near the top of the Powwow in the Wylie Mountains (Hay-Roe, 1957) indicate that it is Late Pennsylvanian or Permian.

In addition to the fusulinids already cited, the following fossils, many of which are silicified, have been reported from rocks of Permian age in the Eagle Mountains: *Schwagerina* sp., *Marginifera* sp., *Dictyoclostus* sp., *Derbya* sp., *Composita* sp., *Pugnax* sp., *Bellerophon* sp., *Omphalotrochus* sp., *Euomphalous* sp., and echinoid spines and plates.

CRETACEOUS ROCKS

Marine Cretaceous rocks, which average about 7,000 feet in thickness and range in age from late Aptian to perhaps as young as late Turonian, were deposited along the eastern margin of the Chihuahua trough; they constitute most of the pre-Cenozoic rocks exposed in the Eagle Mountains and vicinity. The Comanche and Gulf Series, together comprising nine lithologically distinct formations, have been recognized. An unconformity separates the Comanche and Gulf Series in many places in Trans-Pecos Texas and elsewhere but was not observed in the map area. Within the Cretaceous section, there is evidence only for two short periods of erosion: one at the Cox-Finlay contact and the other within the sandstone member of the Benevides Formation. All other formation contacts within the Cretaceous are conformable.

The Cretaceous section shows cyclic lithologic alternation of carbonate and siliciclastic rock. Within the rocks of the Comanche Series four lithologic couplets are represented, each of which consists of siliciclastic rock overlain by carbonate rock. Each unit of a couplet was mapped as a formation.

In the course of the advance of the Cretaceous sea onto the platform and foreland, the Comanche formations overlapped each other and overstepped older formations; thus the basal siliciclastic or marginal facies is younger to the north and east. The age of the basal siliciclastic facies of the Cretaceous System in the Eagle Mountains and vicinity is Aptian; at the Cornudas Mountains about 50 miles north of Sierra Blanca, the age is late Albian.

YUCCA FORMATION

The Yucca Formation includes the oldest Cretaceous rock exposed in the map area; its outcrops are the most widespread, and its red-brown color clearly makes it the most distinctive map unit.

Taff (1891, p. 725) named the Yucca Formation for its excellent exposures on the north face of Yucca Mesa (C-1, 2) where about 1,200 feet of the formation is exposed. The Yucca is sparsely exposed along the northeast face of Front Ridge but is well exposed along the northeast face of Love Hogback (G-6, 7) where the Yucca is protected by the overlying Bluff Formation. Northeast of Devil Ridge a small isolated outcrop (E-8) of Yucca lies just west of Partition tank. The Yucca is widely exposed south and east of the Speck (formerly Love) ranchhouse, where it has been intensely faulted, and it crops out in the thrust sheet along the southwest flank of Back Ridge. Red Hills (H-5, 6) are composed entirely of Yucca, which also crops out in small erosional remnants to the southeast.

Thin beds of gray, brown, and red aphanocrystalline to very finely crystalline limestone and sandy limestone and fine-grained quartz sandstone, equally colorful shale and quartz siltstone, and rather drab limestone-pebble conglomerate compose the Yucca at Yucca Mesa. Limestone, either as an orthochemical precipitate, as the gravel fraction of a conglomerate, or as the clasts of calclithites, constitutes more than half of the Yucca at Yucca Mesa and predominates in the lower half of the formation. Sandstone, at places indistinctly crossbedded and generally spotted with iron oxide, and shale are more abundant in the upper part than in the lower part of the formation. Chert and quartz pebbles are rare in the Yucca outcrops at Yucca Mesa, Front Ridge, and Love Hogback but relatively abundant in the Yucca in the Red Hills and Back Ridge. At Yucca Mesa pisoliths up to an inch in diameter (Md 10 mm) occur about 600 feet above the base in dark gray limestone.

Although the Yucca is largely unfossiliferous, there is a hash of pelecypods and high-spired gastropods in a 6-foot zone about 100 feet below the top. *Arca* sp., *Ostrea* sp., caprinids, *Exogyra*, resembling *Exogyra texana* Roemer, and ostracodes have been reported from the Yucca.

Exposures of Yucca in the Eagle Mountains are few. It crops out in the vicinity of Eagle Spring and just south of the Precambrian outcrop (K-13, 14) where the Yucca disconformably overlies the Permian. The Yucca beds in both of these areas contain more siliceous conglomerate and less limestone than the Yucca at Yucca Mesa, and the formation is much thinner. The thickness of the Yucca near Eagle Spring is 600 to 700 feet; included at the top is a colorful sequence of sandstone, shale, sandy limestone, and limestone-pebble conglomerate that some earlier workers considered to be a basal part of the Bluff.

The disconformable Yucca-Hueco contact is at the surface at only two localities in the map area: near Eagle Spring (H-11, 12) and at the easternmost outcrop of Hueco Limestone (K,L-14).

From the Rhyolite fault north to the end of Espy Ridge, rocks of the Bluff Formation rest on Hueco Limestone. The somewhat anomalous absence of the

Yucca may be the result of non-deposition over a high, or faulting.

In the Indio Mountains, composed largely of the Yucca Formation, the conformable and transitional contact with the overlying Bluff is visible in many parts of the area, but the lower part of the Yucca is everywhere truncated by a fault.

Although several thousand feet of Yucca is probably exposed in the Indios, the maximum thickness that has been measured there is the 2,021 feet that was recorded at MS 9 (S. 7–14.7). There, as throughout the Indios, the Yucca may be grossly subdivided into two units: a lower unit composed of sandstone, conglomeratic sandstone, and conglomerate, and an upper unit composed of sandstone, siltstone, shale, and limestone. The prevailing red-brown color is the most distinctive characteristic.

The sandstone is largely thin-bedded, fine- to medium-grained, moderately to well-sorted grains of quartz cemented by calcite; intergranular iron oxide is abundant. The gravel of the Yucca is largely rounded to subrounded granules and pebbles of gray limestone, pale red and black chert, and white and pink quartz. The shale and siltstone of the upper part of the Yucca characteristically contain rounded calcareous nodules which weather green and accumulate on slopes. The first bed of limestone at MS 9 is slightly more than 200 feet below the next higher one, the base of which was chosen as the Yucca-Bluff contact; this second limestone is 13 feet thick, sandy and very finely crystalline, and contains *Exogyra quitmanensis* Cragin, colonial corals and other fossils. The Yucca-Bluff boundary probably is not everywhere at the same horizon; the zone of transition from uppermost Yucca to the lowermost Bluff has yielded the following: *Actinastrea whitneyi* (Wells), *Actinastrea* n. spp., *Montastrea whitneyi* (Wells), *Montastrea* n. sp., *Complexastrea? glenrosensis* Wells, *Isastrea whitneyi* Wells, *Microsolena texana* Wells, *Helioporidae* sp., *Lamellaerhynchia indi* Ager, *Cyprimeria* sp., *Protocardia* sp., *Unio* sp., *Cardium* sp., *Lima* sp., *Arctica* sp., *Ostrea* sp., *Trigonia mearnsi* Stoyanow, *Trigonia stolleyi* Hill, *Trigonia* sp., *Pecten* (*Neithea*) sp., *Homomya* sp., *Anatina* sp., *Crassaltelites?* sp., *Corbula* sp., *Aptyxiella* sp., *Exogyra* sp., *Exogyra quitmanensis* Cragin, *Toucasia* sp., *Nerinoides roemeri* M. Whitney, *Nerinoides* sp., *Nerinea* sp., *Natica* sp., *Tylostoma* sp., *Turritella* sp., noded gastropod, nautiloid, *Acanthohoplites* sp., *Turrilites* sp., silicified wood.

The age of the Yucca rests mainly on the well-documented "Glen Rose" or early Albian age of the overlying Bluff Formation. By inference, the age of the upper part of the Yucca is late Aptian —early Albian.

BLUFF FORMATION

Bluff Mesa, on the east flank of the northern Quitman Mountains and immediately northwest of 5 Mile Point, is the source of the name "Bluff beds" used by Taff (1891, pp. 726–727). Smith (1940, pp. 609–611, 621–623) applied the name "Bluff Formation" to the beds of sandstone and *Orbitolina*-bearing limestone that are bounded stratigraphically by the colorful limestone and shale of the conformably underlying Yucca Formation and by the light-colored sandstone of the conformably overlying Cox.

In addition to the excellent exposure at Yucca Mesa, the Bluff forms most of the three large outcrops which make up Front Ridge and composes most of Love Hogback. In the Pagoda Hill area where it lies in thrust contact on the Yucca, the Bluff forms prominent ridges. Small west-facing hogbacks of Bluff rise above the alluvial flats south and southeast of Speck Ridge; there are a few low-lying ridges of Bluff southeast of Grayton Lake. Along Love Hogback and Devil Ridge the upper part of the Bluff may thicken to the northwest at the expense of the lower part of the Cox (Smith, 1940, pp. 622–623, 627–628).

The Bluff in the Devil Ridge area is dominantly thin- to thick-bedded, gray, sandy, very finely crystalline limestone with interbeds of light-colored, Cox-like, fine- to coarse-grained, calcareous and siliceous quartz sandstone and some sandy shale. Oolitic limestone occurs about 600 feet above the base (Smith, 1940, p. 610) and about 400 to 700 feet from the top. On the northeast flank of Yucca Mesa, the basal Bluff unit is a dark gray, sandy limestone with abundant oyster fragments. It has a rough weathered surface, and its thickness varies along strike. The lower part of the Bluff is thicker bedded and more resistant than the upper part.

The most diagnostic fossil of the Bluff is the large foraminifer *Orbitolina* d'Orbigny, which is found about 80 feet above the base and at intervals throughout the upper 600 feet of the formation. At Yucca Mesa, the upper *Orbitolina* zone also contains *Porocystis* sp., *Protocardia* sp., gastropods, and echinoids; reef fossils such as *Exogyra* sp., rudistids, and caprinids occur in abundance at horizons throughout the section, along with a variety of other pelecypods, gastropods, and echinoids (Smith, 1940, pp. 620–623). In addition to *Orbitolina*, the microfauna of this upper zone comprises ostracodes, abundant miliolids, and charophytes.

On the northeast flank of the Eagle Mountains, the Bluff is less easily distinguished from the underlying Yucca and the overlying Cox, because there the Bluff contains more sandstone and shale than in the Devil Ridge area. This is to be expected because the Bluff in the Devil Ridge area, with the exception of the small outcrops just south of the railroad, is part of a thrust sheet that moved northeast out of the trough. The Bluff exposed along the northeast flank of the Eagles is beneath the thrust fault and is presumably a nearer-shore facies than most of that in the Devil Ridge area.

At Eagle Spring, limestone of the Bluff caps an east-facing scarp just west and northwest of the Eagle Spring ranchhouse. The Yucca-Bluff boundary was placed at the base of the thick *Orbitolina*-bearing limestone that caps the ridge above and west of the adit at the Eagle Spring fluorspar prospect. About midway in the Bluff section there, *Arctica roemeri* (Cragin), *Tylostoma* sp., and *Anatina* sp. were found, and near the base, *Trigonia* sp.

Limestone of the Bluff Formation is sparsely exposed low on the northwest flank of Lone Hill, and an anomalously thin section is exposed in Espy Ridge where the Bluff overlies the Permian with little, if any, discordance. This may be the result of faulting, or it may be that the Bluff is thinner there than to the northwest or to the south.

From the beds of the lower part of Gillerman's Bluff Mesa in the vicinity of shaft 3 (lower Cox, the writer), Gillerman collected *Orbitolina* sp., *Exogyra quitmanensis* Cragin, and *Porocystis globularis* (Giebel). From limestone beds in the lower part of the Bluff along the Rhyolite fault, *Arctica?* sp., *Anatina* sp., *Exogyra quitmanensis* Cragin, and *Tylostoma* sp. were collected. Pisolitic limestone occurs in the Bluff on Espy Ridge.

Near Eagle Spring and in places southeast along the trace of the Devil Ridge fault, rough-weathering limestone beds of the Bluff overlie the Chispa Summit Formation. This relationship is seen in

Coal Mine Arroyo (H,J-11) just upstream from the old coal mine, around the flanks of TC Peak, and east-southeast K.6–12.9) of Carpenter Spring.

Several relatively small, isolated outcrops of Bluff occur in the Eagle Mountains: in the Black Hill area (M-9), in Rocky Ridge (M-11) between Cottonwood and Broad Canyons (N-11,12), and just east of Cottonwood Canyon on the east and west flanks of Eagle Bluff (M, N-12,13). In the Black Hill area, more than 1,500 feet of thin- to thick-bedded fossiliferous limestone with interbedded shale are overlain disconformably by the well-bedded tuff and tuffaceous breccia of the lower rhyolite. Because of the abundance of *Caprinula* cf. *C. crassificra* (Roemer) and *Toucasia* cf. *T. texana* (Roemer), the lower part resembles reef-limestone zones in the Finlay or even Espy (Gillerman, 1953, p. 17). The upper part of the outcrop, however, is characterized by beds containing abundant *Orbitolina* sp. The Rocky Ridge outcrop of limestone, shale, and sandstone, in plan view roughly 3,500 by 1,500 feet, is highly fractured and has been intruded by a diabase dike. The limestone contains rudistids and caprinids as well as *Orbitolina* sp.; much of the limestone has been crushed, fractured, and recemented. The sandstone and shale are brittle and highly sheared. These rocks rest on the flow rock and pyroclastic rock of the upper rhyolite.

Three similar outcrops of Bluff on the south flank of the Eagles between Broad and Cottonwood canyons are also blocks on the upper rhyolite. In contrast to the outcrop at Rocky Ridge, these exotic blocks are largely limestone. The largest two are triangular in plan; the largest is 4,500 feet long, 3,500 feet wide, and 200 to 300 feet thick. Where the contact is exposed, the limestone and the underlying volcanic rock do not interpenetrate, and the limestone has been only faintly discolored and baked.

Several smaller blocks (M,N-12,13) crop out on the east and west flanks of Eagle Bluff; the largest is about 100 feet thick. While it is possible that the smaller blocks are xenoliths, it is difficult to ascribe that origin to the larger blocks to the west.

In the Indio Mountains, the Bluff crops out widely in the area north of Oxford Springs where it has been highly folded. The most distinctive outcrop of the Bluff in the map area is knife-like Bramblett Ridge (Q,P-12,13) that extends more than 2½ miles northwest from the ranchhouse at Oxford Springs. To the south there are three linear and roughly parallel exposures east of the Indio fault. West of the fault the Bluff is highly faulted, in places folded, and incompletely exposed. The southernmost exposure is in the Lost Valley syncline (W,X-15,16). A small, isolated outcrop of Bluff (V-17) lies just west of Escondido well.

MS 9 includes 796 feet of Bluff. The lowest unit is a 25-foot bed of medium light gray, very finely crystalline, thick-bedded and fossiliferous limestone. Near the base this bed contains *Exogyra quitmanensis* Cragin; next above, a zone of colonial corals, and near the top are *Exogyra* sp., rudistids, and caprinids. Oolitic limestone is characteristic of the lower part of the Bluff. At MS 9 oolitic limestone ranges from about 130 to 285 feet above the base. The ooliths range in diameter from 0.15 to 1.9 mm and in shape from discoidal to oblate spheroidal; they are enclosed in a matrix of sandy and silty sparry calcite.

In the Indio Mountains, *Orbitolina* has been found near the base of the Bluff at the foot of the limestone ridge (T.5–14.8) which leads southeast from the vicinity of the Indio headquarters, from the base of the Bluff in the Lost Valley area, and near the base of the Bluff just east of the Indio fault along the Indio Pass road. At MS 9 the first *Orbitolina* zone is in the upper limestone unit of the Bluff about 730 feet above the base in medium light gray, very finely crystalline, thin-bedded nodular limestone. The first zone bearing abundant *Orbitolina* is 740 feet above the base; *Orbitolina* ranges up to the base of the Cox with locally varied abundance. Also from the uppermost limestone unit of MS 9, *Porocystis globularis* (Giebel), *Tapes* sp., *Anatina* sp., *Trigonia* sp., *Pecten* (*Neithea*) sp., *Cyprimeria* sp., *Tylostoma* sp., *Hemiaster* sp., *Enallaster* sp., and *Holectypus* sp. were collected.

In the Indios, most of the microfauna of the Bluff is confined to the upper part and includes charophytes, ostracodes, and foraminifers, among which are miliolids. In the uppermost part of the Bluff (P.8–15.7) just north of the east end of Oxford Ridge, *Orbitolina* sp., *Trigonia* sp., and *Loriolia* sp. were collected. The upper part of the Bluff also characteristically yields large, cardid clams and bulbous gastropods.

Between the lower and upper limestone sections of the Bluff, beds of thin-bedded, light gray, very finely crystalline, fossiliferous limestone alternate with beds of thin-bedded, gray, fine- to medium-grained, moderately to well-sorted and subangular to subrounded quartz sandstone. Calcareous cement binds the grains; much of the sandstone resembles Cox.

The Bluff in the Lost Valley area is only 446 feet thick; the uppermost limestone containing the *Orbitolina* zone is 140 feet thick, and the alternating limestone and sandstone and sandy limestone of the lower part is 306 feet thick (Braithwaite, 1958, pp. 18–19). At the base is a gray, 50-foot rudistid-reef limestone. Adams (1953, p. 23) collected *Hemiaster* sp. and *Ostrea* sp. from the basal unit and *Tylostoma* sp., *Trigonia* sp., and *Homomya* sp. from the upper *Orbitolina* zone in the Lost Valley area.

The Bluff Formation of the Eagle Mountains and vicinity contains *Orbitolina* sp. and is therefore paleontologically correlative with the Glen Rose Limestone of central Texas, the age of which is early Albian.

COX SANDSTONE

The Cox Sandstone is an excellent stratigraphic marker because of its lithologic and color contrast with the gray limestone of both the underlying Bluff Formation and the overlying Finlay Limestone. Richardson (1904, p. 47) named this unit the "Cox formation," taking the name from Cox Mountain (Tabernacle Mountain), about 16 miles northeast of Sierra Blanca.

In the Devil Ridge area, relatively small outcrops of Cox are on the northeast flanks of Sand Mountain and Texas Mountain, but on Devil Ridge the Cox forms the major and the highest part of this 7.5-mile-long hogback. The Cox is poorly exposed in a low ridge southeast of Grayton and well exposed but folded and faulted in Little Hill (F,G-9,10). The formation is also exposed in the eroded crest of the overturned anticline in Back Ridge and in the general area east and southeast of the Speck ranchhouse. Two small hills of Cox Sandstone rise above the gravel and alluvium just west of Love Hogback.

The Cox thickens rapidly southeast along strike from 557 feet near Yucca Mesa (Smith, 1940, p. 612) to 1,737 feet at MS 16, about 6.5 miles southeast. Because the Bluff thickens to the northwest, the lower part of the Cox may grade northwestward into the upper part of the Bluff. A gray, nodular, fossiliferous limestone in the upper part of the Cox separates the unfossiliferous upper and lower sections of sandstone; shale occurs near the base. In the Devil Ridge area, the sandstone of the Cox is various shades of gray, brown, orange, and pink and is characterized by spots of intergranular, reddish-orange iron oxide averaging 2 mm or less in diameter. Fine to medium-grained quartz composes the bulk of the formation, although it does contain beds of limestone as well as shale. The sandstone at Sand Mountain and at Flat Mesa is coarser and less indurated than that on Devil Ridge (Smith, 1940, p. 611). The Cox contains a few local lenses of limestone, quartz, and chert pebble conglomerate. The formation is thin bedded as well as cross-bedded and contains oscillation ripple marks.

Throughout the lower 200 feet, sandstone and limestone are interbedded; covered zones are very likely shale. Beginning about 985 feet above the base, however, beds of dark gray nodular limestone contain abundant *Actaeonella dolium* Roemer as well as *Nerinea* sp., *Tylostoma* sp., *Gryphaea* sp., and *Exogyra* sp. *Pecten* (*Neithea*) *irregularis* Böse occurs about 1,050 feet above the base, *Exogyra texana* Roemer and caprinids about 1,080 feet above the base, and *Gryphaea mucronata* Gabb at about 1,255 feet above the base, all in thin-bedded, nodular limestone. Smith (1940, p. 612) collected *Engonoceras* sp. from a thin, sandy limestone bed about 650 feet above the base of the Cox some 2 miles northwest of MS 16. From about the same horizon he also collected *Actaeonella texana* (Roemer), presumably the same as *Actaeonella dolium* Roemer.

The Cox is widely exposed in the Eagle Mountains. From just west of Eagle Spring the Cox outcrop extends in a broken but broad band along the northeast flank of the mountains. The Cox is also prominently exposed in Lone Hill; it makes up the upper part of Espy Ridge and most of the ridge that flanks Spar Valley on the north; and it is widely exposed south of the mouth of Spar Valley. The beds dip generally southwest and have been intruded by rhyolite sills, most of which are too small to show on the map.

A complete section of Cox is not exposed in the Eagles, but well over 1,000 feet crop out in the Spar Valley area. As in the Devil Ridge area, the Cox is a well-indurated, fine- to medium-grained sandstone but with more conglomeratic lenses scattered throughout. Ripple marks, burrows and trails, and cross-beds are common features. Sandstone of the Cox is characteristically desert-varnished.

A few beds of gray, nodular limestone in the vicinity of shaft 3 yielded *Exogyra texana* Roemer, *Protocardia* sp., *Ostrea* sp., *Nerinea* sp., *Tylostoma* sp., and *Anatina*? sp. The Cox contains silicified wood.

Platy, angular fragments of the sandstone predominate in the colluvium of the Cox and mask less resistant rock. This gives the erroneous impression that the Cox is 100 percent sandstone, whereas shale and limestone interbeds are common.

Small xenoliths(?) of white, highly brecciated and re-cemented Cox sandstone are exposed southeast of East mill, where they crop out within the upper rhyolite. The largest of these blocks has a maximum dimension of about 500 feet; most are much smaller.

In the Indio Mountains, the Cox is present in the folded area north and northeast of Oxford Spring, in the principal ridges of the mountains south of Squaw Peak where thrust faults have resulted in two roughly parallel en echelon exposures. The Cox is also exposed along the east margin of the mountains and in the Lost Valley area.

At MS 10 (S.8–15.4) about a mile southeast of Squaw Spring, the Cox is 1,267 feet thick. Although generally light colored, in detail its color ranges from white through different shades of gray, orange, and brown. Colors of weathered surfaces are equally varied. Sandstone of the Cox is largely fine- to medium-grained quartz cemented by calcite but mostly silica in the form of overgrowths on quartz grains.

Spots of intergranular iron oxide are common throughout the section. Beds of conglomerate are rare, but there are several conglomeratic sandstone lenses with a gravel fraction composed of rounded quartz, chert, and limestone granules and pebbles. Such features as cross-beds, ripple marks, and penecontemporaneous slump folds are present. The 9-foot, medium light gray, very finely crystalline limestone about 1,015 feet above the base contains the following fossils: *Exogyra texana* Roemer, *Gryphaea washitaensis* Hill, *Toucasia* sp., *Arctica?* sp., caprinid, *Exogyra* cf. *E. texana* Roemer. *Actaeonella* sp. was collected near the north end of Red Mountain from Cox that has been overridden by a thrust sheet of Yucca that moved east. There are other thin beds of limestone in the Cox, but they are largely covered. Near the base of the Cox, also largely covered in all but a few localities, is a red, brown, and green shale. The Cox-Finlay contact in widely separated areas in Trans-Pecos Texas (including the Indio Mountains) has been reported to be disconformable. At MS 5, there is a 1-inch caliche zone at the Cox-Finlay contact.

Braithwaite (1958, p. 30) reported 1,592 feet of Cox in the Lost Valley area in the southern Indios. The section is largely sandstone with some conglomerate plus a total of 79 feet of limestone and 5 feet of shale.

The upper part of the Cox is paleontologically correlative with the Fredericksburg Group of central Texas; the lower part may be correlative with the upper Trinity. The age of the Cox is Albian.

FINLAY LIMESTONE

The massive, gray beds of limestone that form the outer rim of the Finlay Mountains, about 20 miles northwest of Sierra Blanca, Texas, were named the Finlay Formation by Richardson (1904, p. 47).

In the northwest part of the Devil Ridge area, the Finlay Limestone crops out at Texan Mountain and at Sand Mountain and in three southeast-trending, roughly parallel exposures to the south and east. A small outcrop (G-5) of Finlay lies on the north flank of Red Hills. In the Black Butte and Speck Ridge area, it is the most conspicuous formation exposed in the near-vertical ridges and plunging folds.

Nowhere in the Devil Ridge area is a complete section of Finlay exposed. The 588 feet in MS 16 is a medium gray, pale yellowish-brown-weathering, thin-to thick-bedded, very finely crystalline, nodular limestone with a few thin beds of shale, siltstone, and very fine-grained quartz sandstone near the base. There is a 5-foot zone of brown-weathering, irregular, rounded chert nodules about 530 feet above the base of the formation.

The Finlay forms a series of resistant ledges separated by less resistant and characteristically covered beds; it weathers to a rough surface owing mainly to the dissolving action of meteoric water. At the northwesternmost outcrop (D.4–2.2) of Finlay on Devil Ridge, solution furrows are unusually well developed; the almost flat-lying Finlay surfaces exposed south of Grayton Lake show extensive development of solution pits.

The most diagnostic fossil of the Finlay is the foraminifer *Dictyoconus walnutensis* (Carsey), which at MS 16 occurs in a zone about 17 feet thick beginning about 355 feet above the base of the Finlay. *Exogyra texana* Roemer occurs throughout the Finlay.

At or near MS 16, *Engonoceras* sp. was found about 50 feet above the base and *Oxytropidoceras* cf. *O. chihuahuaensis* Adkins was collected about 470 feet above the base of the Finlay. The lower 100 feet of the Finlay at MS 16 is typified by thin beds of oyster hash (probably *Exoygra* sp.). A 9-foot zone of rudistids and caprinids begins about 400 feet above the base and a second zone, approximately 5 feet thick, begins about 580 feet above the base.

At JUDGE triangulation station (K.3–8.8), the underlying Finlay yielded *Toucasia* aff. *T. texana* (Roemer); 10 feet below is a zone of *Dictyoconus walnutensis* (Carsey). *Tylostoma* sp., *Lunatia* sp., and *Nerinea* sp. were collected just below the *Dictyoconus* zone. *Haplostiche texana* (Conrad) has also been reported from the Finlay (Smith, 1940, p. 615).

The lithology, fauna, and weathering habit of the Finlay in the Eagle Mountains is much like that in Devil Ridge, but a complete section is not exposed. In the Eagles, the Finlay is exposed in the Lucky Strike prospect and the Spar Valley area. It is everywhere faulted against younger rock.

Gillerman (1953, p. 24) reported the occurrence of corals in the zone of *Toucasia texana* (Roemer) 105 feet above the base of his measured section 4 in the Lucky Strike area. *Requienia* sp., presumably from this zone, were collected from the Finlay south of the mouth of Spar Valley. Gillerman (1953, p. 23) also reported the presence locally of oolitic limestone in the interval above the "*Toucasia*-reef beds."

In the Indio Mountains south of Squaw Peak, the Finlay, repeated by a thrust fault, crops out in two en echelon exposures. The resistant limestone forms west-facing hogbacks and ridges; the west wall of Snake Canyon is a dip slope of Finlay. The formation is also well exposed in the Lost Valley area; there, as along the westernmost of the two outcrops to the north, there are complete sections of the Finlay.

At MS 5 (S.8–15.8) there is 401 feet of Finlay. The Finlay is much thicker in the Lost Valley area where Braithwaite (1958, p. 36) reported 797 feet. The sections south of Snake Canyon, however, are on blocks which were thrust northeast. These sections, therefore, are from farther out in the trough and greater thicknesses are to be expected.

At MS 5 the Finlay is a medium gray to light brownish-gray, thin- to thick-bedded, very finely crystalline limestone that weathers to a very pale orange and grayish-orange, rough surface. The lower 8.5 feet of the Finlay is a yellowish-gray siltstone; an 8-foot grayish-orange, fine-grained sandstone begins about 45 feet above the base.

The Finlay contains abundant micro- and macrofossils. As in areas to the north and northwest, the most diagnostic fossil is *Dictyoconus walnutensis* (Carsey), which occurs in a 45-foot zone beginning about 223 feet above the base of the Finlay. *Engonoceras* sp. was collected from zones 53 to 125 feet and 193 to 224 feet above the base, and *Pervinquieria* sp. from a zone 315 to 355 feet above the base of the Finlay. Reef fossils are characteristic of the upper 300 feet of the Finlay. *Touscasia texana* (Roemer), *Requienia* sp., *Monopleura* sp., *Eoradiolites* sp., radiolitids, rudistids, caprinids, *Exogyra texana* Roemer, and *Exogyra* sp. were collected from the upper 300 feet of MS 5. Adams (1953, pp. 34–35) collected *Alectryonia carinata* (Lamarck) from this same zone in Lost Valley. Braithwaite (1958, p. 39) reported the occurrence of *Eoradiolites davidsoni* (Hill), *Toucasia patagiata* (C. A. White), and *Toucasia* aff. *T. texana* (Roemer) in the upper 150 feet of the Finlay in Lost Valley. *Lunatia* sp., which is common in the Glen Rose of central Texas, occurs in the lower half of the Finlay throughout the Eagle Mountains and vicinity.

The age of the Finlay Limestone is middle Albian, and it is paleontologically correlative with the Fredericksburg Group of central Texas, that is, the Walnut, Comanche Peak, and Edwards formations. Because the upper part of the Cox may be synchronous with the lower part of the Fredericksburg of central Texas, the Finlay of Trans-Pecos Texas may be synchronous with all but the lowest part of the Fredericksburg Group of central Texas.

BENEVIDES FORMATION

The Benevides Formation, a thin sequence of non-resistant siltstone and overlying ledge-forming sandstone, is one of several siliciclastic units in the map area that separate carbonate units of the Comanche Series.

The largest outcrops (D-6) of the Benevides in the Devil Ridge area are just south of Grayton Lake where grayish-pink, pinkish-gray, and pale red fine-grained, calcareous and somewhat argillaceous and friable quartz sandstone is poorly exposed in the flat between ridges of Finlay and Espy Limestone. South-southeast of Grayton, sandstone that crops out in the drainage channels that lead west into Triple tanks may also be Benevides.

The poorly exposed very pale orange and pinkish-gray, fine- to medium-grained, calcareous and somewhat argillaceous, well-indurated quartz sandstone that crops out (B.4–2.6) near the Speck ranchhouse is mapped as Benevides. The identification is based solely on superposition and lithology; no fossils were recovered.

In the Eagle Mountains, interbedded black, gray, and yellow siltstone and black, nodular limestone of the Benevides are exposed in a small fault slice west of Espy Ridge. This locality has yielded the following: *Exogyra plexa* Cragin, *Exogyra texana* Roemer, *Gryphaea navia* Hall, *Gryphaea corrugata* Say, *Pecten* (*Neithea*) cf. *P. subalpina* (Böse), *Pecten* (*Neithea*) sp., *Sphaera?* sp., *Cerithium?* cf. *C. bosquense* Shumard, *Tylostoma* sp., *Oxytropidoceras belknapi* (Marcou), *O. geniculatum* Conrad, *O. oravocense* (Böse), *Oxytropidoceras* aff. *O. trinitense* (Gabb), *Oxytropidoceras* cf. *O. autocarinatum* (Shumard), *Oxytropidoceras* sp., and a brachiopod(?).

At MS 8 on the east flank of the Eagles in the valley bordered on the southwest by Wyche Ridge, 56 feet of Benevides was measured. Olive-gray and black sandy quartz siltstone is interbedded with sandy very finely crystalline nodular limestone. This is overlain by 28 feet of fine- to coarse-grained calcareous quartz sandstone. Near the top, calcareous cement is replaced by siliceous and iron oxide cement; the sandstone appears to be "case hardened" and is widely stained by iron oxide. The sandstone has been intruded by a sill of lower rhyolite 25 feet thick, above which more of the sandstone of the upper member is sparsely exposed. Fossils collected from this locality are: *Craginites* sp., *Pecten* (*Neithea*) sp., *Pervinquieria* sp., and *Pervinquieria?* sp. A short distance northwest of MS 8, the sandstone member of the Benevides is poorly exposed at intervals in the bed and bank of one of the main drainage channels.

Probably the most typical exposure of the Benevides occurs in the Indio Mountains in an outcrop extending south-southeast from the Squaw Spring fault. The lower, non-resistant shale member forms an alluvium-covered strike valley, whereas the upper very pale orange to pinkish-gray sandstone member forms a resistant ledge. At MS 5, the Benevides is 121 feet thick; only the sandstone member, 33 feet thick, is exposed. This upper part is fine- to medium-grained, calcareous, quartz sandstone; it is thin to thick bedded and cross-bedded. The lower part of this upper member is characterized by abundant, roughly spherical, calcite-cemented, fine-grained quartz sandstone nodules up to 12 cm across (Md 5 cm).

At the mouth of Snake Canyon, 8 to 10 feet below the top of the sandstone member, there is a slightly uneven surface that has been bored, probably by crabs, and the cross-beds of the underlying unit have been truncated and channeled. Primary bedding above and below the disconformity or diastem is concordant. There are three small outcrops in the Lost Valley area, where the formation is largely covered by terrace gravel, alluvium, and volcanic rock.

The Benevides is paleontologically correlative with the Kiamichi of north-central Texas and possibly with the lower part of the Duck Creek Formation as well. The age is upper Albian.

ESPY LIMESTONE

Huffington (1943, p. 1005) proposed the name "Espy Formation" for "the Washita beds mapped by Smith (1940, pl. 1) east of Love Hogback and the southeastern part of Devil Ridge." Because of the distinctive, brown-weathering sandstone (the Eagle Mountains Sandstone) in the upper part of Huffington's Espy and Smith's Washita, the section is easily divisible into three units. It is proposed to restrict the term "Espy Limestone" to that body of rock between the Benevides Formation and the Eagle Mountains Sandstone. The type section is that rock exposed at MS 11 and MS 11a (G-8).

The Espy crops out in a series of low, northeast-facing hogbacks east of Devil Ridge and Love Hogback. MS 11 (G.0–8.8) records 2,193 feet of Espy; this measurement includes inferred thicknesses of alluvium-covered flats between the hogbacks. The thickness of the exposed strata in the low ridges of limestone is 736 feet. The estimated total thickness of Espy Limestone of 2,193 feet is probably a maximum, because the measured section crosses a number of faults. On the other hand, the base of the Espy is not exposed, and the measurement does not include all the formation.

The Espy in Devil Ridge is largely medium light gray to brownish-gray, very finely crystalline, thin-bedded, fossiliferous limestone interbedded with less resistant marl. Color of weathered surfaces is typically very pale orange. Iron oxide pseudomorphs after pyrite are common. The lowermost part of the Espy is black shale interbedded with thin beds of nodular limestone and is exposed in only one place (J.4–9.1) where colluvium has slipped downward on a steep slope.

Fossils in the Espy exposed along MS 11 (G.0–8.8) in the Devil Ridge area were collected from five zones, as follows: (1) lower 50 feet—*Gryphaea washitaensis* Hill, *Nerinoides* sp., *Engonoceras* sp., *Mortoniceras* sp., *Pervinquieria* sp.; (2) 430 to 530 feet above the base—*Pecten (Neithea) texanus* (Roemer), *Pecten (Neithea) georgetownensis* Kniker, *Cyprimeria* sp., *Gryphaea washitaensis* Hill, *Mortoniceras* cf. *M. wintoni* (Adkins), *Mortoniceras* sp., *Drakeoceras* cf. *D. drakei* Young, *Drakeoceras* cf. *D. gabrielensis* Young, *Drakeoceras* sp., *Paracymatoceras texanum* (Shumard), *Pervinquieria* cf. *P. trinodosa* (Böse), *Eutrephoceras* sp., *Enallaster* sp., *Epiaster elegans, Holaster simplex* Shumard; (3) 1,510 to 1,660 feet above the base—*Prohysteroceras* sp., *Holectypus* sp.; (4) 1,825 to 1,900 feet above the base—*Lima wacoensis* Roemer, *Pecten (Neithea) georgetownensis* Kniker, *Pervinquieria* sp., *Tetragramma* sp., *Enallaster* sp., *Pedinopsis* sp.; (5) upper 100 feet—*Toucasia* sp., caprinids, *Nerinea* sp., *Nerinoides* sp., *Mortoniceras* sp., *Enallaster* sp., *Pedinopsis* sp. The following are some of the fossils collected from MS 11a: *Haplostiche texana* (Conrad), *Kingena wacoensis* (Roemer), *Gryphaea washitaensis* Hill, *Pecten (Neithea) texanus* (Roemer), *Pecten (Neithea) georgetownensis* Kniker, *Protocardia texana* (Conrad), *Mortoniceras* cf. *M. wintoni* (Adkins), *Mortoniceras* sp., *Plesioturrilites brazoensis* (Roemer), *Plesioturrilites* sp., *Paracymatoceras* sp., *Enallaster sp., Holectypus* sp., and *Pedinopsis* sp.

The Espy crops out in the tight, synclinal fold in the limestone at the base of Black Butte (K.0–9.0), in the Indian Springs area (J-8,9), and on the steep cliffs that form the west flank of the Eagles. Because of the similarity in lithology and the presence of *Kingena wacoensis* (Roemer), the Espy exposed in the immediate vicinity of Indian Springs is roughly correlative with that exposed at MS 11a. The sharply folded limestone beneath Black Butte was identified as Espy on the basis of the occurrence there of *Gryphaea washitaensis* Hill, *Pecten (Neithea) georgetownensis* Kniker, *Nerinoides* sp., *Nerinea* sp., *Enallaster* sp., *Pedinopsis* sp., and *Hemiaster* sp. The occurrence of *Kingena wacoensis* (Roemer), *Gryphaea* aff. *G. graysonana* Stanton, *Pecten (Neithea) georgetownensis* Kniker, and *Pedinopsis* sp. in the gently dipping limestone beds that crop out in the cliffs that form the west flank of the Eagles identifies those beds as Espy.

Gillerman (1953, pp. 30–31) collected fossils from the uppermost Espy (his reef limestone member of the Grayson Formation) in the low ridges on the northeast flank of Devil Ridge. These fossils included a varied collection of corals, among which J. W. Wells recognized 15 genera and named 9 new species.

Poorly exposed limestone beds (B.9–2.3) north of Yucca Mesa are shown on the map as Espy on the basis of lithology and stratigraphic position. No diagnostic fossils were found there.

In the Carpenter Spring area and in Wyche Ridge, the Espy has been repeated by the Carpenter fault; in Wyche Ridge, the Espy has been intruded by sills of lower rhyolite as well as by dikes of a dark green rock. In the Eagle Mountains, the thickness of the Espy stratigraphic interval is about 950 feet. The lower 800 feet of the section is interbedded gray shale and black limestone, the lower half of which yielded, in Carpenter Canyon and near the Lucky Strike prospect, *Kingena* sp., *Ostrea (Arctostrea) carinata* (Lamarck), *Gryphaea washitaensis* Hill, *Pecten (Neithea) subalpinus* (Böse), *Pecten (Neithea) texanus* (Roemer), *Pervinquieria* cf. *P. kiliani* (Lasswitz), *Pervinquieria* cf. *P. trinodosa* (Böse), *Pervinquieria* sp., *Eopachydiscus* cf. *E. brazoense* (Shumard), and many others (Gillerman, 1953, pp. 25–26). The succeeding 90 feet of nodular, thin-bedded, black limestone

(Gillerman's "Carpenter Limestone Member of the Grayson Formation") is very fossiliferous in Carpenter Canyon where *Kingena* sp., *Exogyra arietina* Roemer, and *Exogyra drakei* Cragin were collected (Gillerman, 1953, pp. 24–30). This is overlain by about 60 feet of massive, gray, rough-weathering limestone (Gillerman's "reef-limestone member of the Grayson Formation") which is characterized by abundant caprinids and rudistids.

Espy exposed along the northwest end of the spur road to the Lucky Strike prospect yielded *Beudanticeras* sp., *Eopachydiscus* sp., *Mortoniceras* sp., *Pervinquieria* aff. *P. equidistans* (Cragin), *Eopachydiscus* sp., and *Mortoniceras* sp.

One isolated, linear outcrop of limestone (N-13) low on the southern flank of the Eagles beneath Eagle Bluff is mapped as Espy because it yielded *Pedinopsis* sp.

At the mouth of Broad Canyon the road crosses an outcrop of gray limestone. No diagnostic fossils were found, but the rock resembles the Espy Limestone. Because well-bedded and interbedded volcanic and sedimentary rocks underlie this block of limestone and because the attitude of these beds differs from that of the beds of limestone, the limestone block may be a xenolith or its origin may be similar to that of the erratic blocks of the Bluff Formation. It is also possible that this block of Espy is in normal or slightly faulted position stratigraphically above the Finlay that crops out immediately to the west.

In the Indio Mountains, the upper strata of the Espy form the major part of Willoughby Ridge, in which all formations are overturned; the high ridge east of Green Peak is made up largely of the Espy, the upper part of which is characteristically thicker bedded and more resistant than the lower part. Espy also crops out in the Lost Valley area, in a small window (V.3–17.2) in the thrust sheet, and in a small outcrop (S.4–17.1) just west of Green River.

The color of the Espy in the Indio Mountains ranges from medium dark gray to light brownish gray, and the rock weathers very pale orange and yellowish brown. It is very finely crystalline and thin to thick bedded; karren are common on weathered surfaces. The Espy is 1,094 feet thick at MS 6; however, the line of section crosses a fault of unknown magnitude.

The shale and interbedded nodular limestone and marl of the lower 50 to 60 feet of the Espy are very fossiliferous, especially in the Lost Valley area. The following fossils were collected from this zone: *Kingena wacoensis* (Roemer), *Pecten* (*Neithea*) *texanus* (Roemer), *Gryphaea washitaensis* Hill, *Trigonia stolleyi* Hill, *Pervinquieria equidistans* (Cragin), *Pervinquieria* aff. *P. equidistans* (Cragin), *Pervinquieria* sp., *Pervinquieria?* sp., *Craginites?* sp., *Eopachydiscus* sp., *Eopachydiscus?* sp., *Idiohamites* sp., *Idiohamites?* sp., *Goodhallites* aff. *G. aguilerae* (Böse), *Pervinquieria* cf. *P. equidistans* (Cragin), *Mortoniceras* sp., *Mortoniceras?* sp., *Beudanticeras* sp., *Elobiceras* sp., *Hemiaster* cf. *H. elegans* Shumard, *Hemiaster* sp., *Holaster simplex* Shumard, *Epiaster* sp. This zone also yielded *Prohysteroceras* sp., *Eopachydiscus brazoense* (Shumard), *Mortoniceras* aff. *shumardi* (Marcou), and *Pedinopsis* aff. *P. symmetrica* (Cragin) (Braithwaite, 1958, pp. 47–48).

At MS 6 (T.4–16.3), the thick-bedded, more resistant limestone beds from about 460 to 720 feet above the base yielded the following: *Pecten* (*Neithea*) *georgetownensis* Kniker, *Pecten* (*Neithea*) *roemeri* Hill, *Pholadomya* cf. *P. sancti-sabae* Roemer, *Gryphaea washitaenis* Hill, *Salenia* sp., *Turritella* sp., *Nerinea* sp., *Tylostoma* sp., *Alepes* sp., *Drakeoceras drakei* Young, *Drakeoceras* sp., *Cymatoceras* sp., *Pervinquieria equidistans* (Cragin), *Holectypus* cf. *H. planatus* Roemer, *Holectypus* sp., *Enallaster* sp., *Tetragramma* sp., *Pedinopsis* sp., and *Hemiaster* sp. Large rudistids occur from about 735 to 770 feet above the base of the formation. An upper 194-foot fossiliferous zone extends from about 900 feet above the base to the top of the formation; about the upper 95 feet are characterized by rudistids and caprinids as well as by *Gryphaea washitaensis* Hill, *Pecten* (*Neithea*) *georgetownensis* Kniker, *Pecten* (*Neithea*) sp., *Pholadomya sancti-sabae* Roemer, *Tylostoma* sp., *Turritella* sp., and *Enallaster* sp.

The isolated outcrop of Espy Limestone just west of the road leading north from the Rio Grande to Lost Valley yielded these fossils: *Pervinquieria equidistans* (Cragin), *Pervinquieria* cf. *P. equidistans* (Cragin), *Mortoniceras* sp., *Epiaster* cf. *E. elegans*, *Epiaster* sp., *Enallaster* sp., and *Tetragramma* sp.

The identification of the limestone outcrop (V.8–17.0) immediately east of Campo Bonito as Espy is questionable, because the lithology is not definitive and only the following fossils were found there: *Exogyra* sp., *Nerinoides* sp., gastropods, *Hemiaster* sp., and *Enallaster* sp. North of the water gap in this limestone outcrop, there are brown-weathering nodules of chert which resemble silicified rudistids and caprinids.

The age of the Espy is late Albian to early Cenomanian; it is paleontologically correlative with the Georgetown Limestone of central Texas and is approximately paleontologically correlative with part of the Duck Creek, as well as the Fort Worth, Denton, Weno, Pawpaw, and Main Street Formations of northeast Texas.

EAGLE MOUNTAINS SANDSTONE

The platy, orange- and brown-weathering, calcareous Eagle Mountains Sandstone is in color, lithologic, and faunal contrast to the conformably underlying and overlying gray Comanche limestone. Gillerman (1953, p. 27) divided his Grayson Formation in the Eagle Mountains into three members on "lithological and faunal bases." From oldest to youngest they are the "Carpenter limestone member," the "reef-limestone member," and the "Eagle Mountains sandstone member." He described the youngest as follows (1953, p. 31):

> . . . a distinct and persistent member . . . found throughout the mapped area adjacent to the reef-limestone member except where rhyolite intervenes. About 70 feet of interbedded brown sandstone (some of which are quartzitic), brown shales, siltstone, and sandy limestones make up the member. The characteristic brown color of the beds contrasts strongly with the dominant blue-gray color of the other formations of late Comanche age. *Exogyra cartledgi* [sic] Böse is characteristic of the Eagle Mountains member and is abundant in the beds immediately overlying the reef-limestone member. Other fossils identified are *Protocardia* sp. and *Trigonia?* sp.

Type section of the three members was designated as Carpenter Canyon, about a mile above Carpenter wells (Gillerman, 1953, p. 27).

The Eagle Mountains Sandstone is here considered as a formation. It comprises that sequence of orange- and brown-weathering interbedded sandy limestone, calcareous sandstone, and shale that rests on the gray limestone of the Espy and that is overlain by the nodular, gray limestone of the Buda.

In the Devil Ridge area, the Eagle Mountains Sandstone crops out in the low northwest-trending hills east of Devil

Ridge, Love Hogback, and the Speck ranchhouse. At MS 12 (E.7–8.7) there are 130 feet of Eagle Mountains Sandstone, much of it covered. Of the part exposed, nearly 80 percent is brown-weathering, very fine-grained quartz sandstone with calcareous and iron oxide cement. The rock is characteristically thin bedded as well as laminated and cross-laminated. Platy, angular fragments of the sandstone litter the surface and are locally desert-varnished.

Exogyra cartledgei Böse in great abundance and *Gryphaea graysonana* occur about 10 feet above the base of the formation in a 1-foot oyster hash. Numerous small unidentified clams averaging about 7.5 mm in maximum dimension occur at intervals through the formation. Weathered surfaces of the lowermost sandstone unit characteristically show small heart-shaped depressions, averaging 13 to 15 mm wide and 0 to 10 mm deep, that may be clam burrows.

The Eagle Mountains Sandstone crops out southeast of Eagle Spring in a ridge that runs parallel to and just west of the northwest-trending part of the Lone Hill fault. Farther southeast, the Eagle Mountains Sandstone is exposed in the Carpenter Spring area and along Wyche Ridge; in both areas it is repeated by a high-angle thrust fault.

South in the Indio Mountains, the Eagle Mountains Sandstone is sparsely exposed in an overturned attitude along the west flank of Willoughby Ridge, east-northeast of Green Peak where it crops out low on the east flank of the highest ridge of the southern Indio Mountains, in the highly folded inlier west of Escondido well, and just north of the Rio Grande in the Lost Valley area.

At MS 6 in the southern Indio Mountains, the Eagle Mountains Sandstone is 78 feet thick. Twenty percent of the section is covered, but of the exposed part 90 percent is orange- and brown-weathering sandstone or sandy limestone similar to that at MS 12. Within about 17 feet of the base of the formation at MS 6, the large, agglutinated foraminifer *Haplostiche texana* (Conrad) occurs with *Exogyra cartledgei* Böse. At an outcrop of brown sandstone just north of the Rio Grande and immediately east of the road that leads north to the Lost Valley area, *Exogyra cartledgei* Böse and *Gryphaea graysonana* Stanton have been collected; *Metengonoceras* sp. was also found in the Eagle Mountains Sandstone in the southern Indios (Braithwaite, 1958, p. 50).

The Eagle Mountains Sandstone is paleontologically correlative with the Del Rio Clay of southwest Texas, but proof of lateral continuity between the Del Rio Clay and the Eagle Mountains Sandstone is lacking. The age of the Eagle Mountains Sandstone is early Cenomanian.

BUDA LIMESTONE

The top of the Buda Limestone coincides with the top of the Comanche Series in the map area. The gray, nodular limestone of the Buda, where it is exposed along with the underlying Eagle Mountains Sandstone and overlying Chispa Summit shale, stands out in marked contrast to those orange- and brown-weathering siliciclastic units. Lithologically, the Buda and Espy Limestones are not easily distinguished.

In the Devil Ridge area, the Buda crops out in the hills northeast of Devil Ridge, Love Hogback, and the Speck ranchhouse. In the Eagle Mountains, the Buda crops out in the Carpenter Spring area and along Wyche Ridge; it has been repeated in both areas by the Carpenter fault. The Buda crops out in the Indio Mountains in an overturned position along Willoughby Ridge and in two small outcrops (T-16, 17) just east of the high, north-trending ridge in the mountains.

The Buda is 239 feet thick at MS 12 (G.7–8.7) in the Devil Ridge area, 225 feet thick in Carpenter Canyon (Gillerman, 1953, p. 31), and 218 feet thick at MS 6 (T.4–16.3) in the Indio Mountains, where the upper part is truncated by a thrust fault. In the few places where the contact of the Buda and Chispa Summit is exposed, evidence of an unconformity is lacking.

The Buda is a characteristically light brownish-gray, very finely crystalline, nodular, thin-bedded limestone that weathers very pale orange to pale yellowish brown. Microscopic shell fragments, largely gastropods and pelecypods, and foraminifers occur in varied abundance throughout the Buda. Macrofossils are sparse in the Buda in the Indio Mountains, although the lower 46 feet of MS 6 yielded *Pecten* (*Neithea*) sp., *Alectryonia* cf. *A. carinata* Lamarck, *Turritella* sp., and *Hemiaster* sp. At or in the vicinity of MS 12 in the Devil Ridge area, the lower part of the Buda contains abundant macrofossils, including *Cyprimeria* sp., *Pholadomya* sp., *Pecten* (*Neithea*) sp., *Trigonia* sp., *Anchura* sp., *Turritella* sp., *Tylostoma* sp., *Budaiceras* sp., and *Enallaster* sp.

From Carpenter Canyon, Gillerman (1953, p. 31) reported *Lima shumardi* Shattuck, *Pholadomya shattucki* Böse, *Isocardia* sp., *Exogyra* sp., *Turritella* sp., *Nerinea* sp., *Tylostoma* cf. *T. harrisi* Whitney, and *Enallaster texanus* (Roemer). In addition, he cited the occurrence of a persistent bed of *Turritella* and *Nerinea* at the base of the formation immediately above the Eagle Mountains Sandstone. Immediately northeast of the Carpenter fault, the uppermost Buda contains abundant turritelid gastropods.

Buda is the only central Texas name that has been used in the map area. The formation can be traced from central Texas into western Trans-Pecos Texas and very likely was once a continuous body of rock. The age of the Buda is Cenomanian; its top in Trans-Pecos Texas, northern Chihuahua, and in central Texas coincides with the top of the Comanche Series.

CHISPA SUMMIT FORMATION

The Chispa Summit Formation includes the youngest Cretaceous rock exposed in the Eagle Mountains and vicinity. The base of the Chispa Summit coincides with the base of the Gulf Series; it is generally covered. Adkins (1933, p. 437) proposed the name for the approximately 800 feet of yellow and brown interbedded, flaggy limestone, marl, and clay that crop out near Chispa Summit about 20 miles south-southeast of Eagle Peak.

In the Devil Ridge area, the Chispa Summit Formation is sparsely exposed in small outcrops northwest of Lucky Well and along the northeast flank of Love Hogback where it is in thrust contact with the Yucca Formation; in the valley east of the Speck ranchhouse, about 1,600 feet of Chispa Summit may be present. Much of it is covered by gravel and alluvium, and it has been intruded by dikes and sills of mid-Tertiary igneous rock. East of the Speck ranchhouse, the Chispa Summit is thin bedded and calcareous and grades upward from gray and black fissile shale and flaggy limestone at the base through poorly exposed interbedded shale and sandy shale, to interbedded fine- to coarse-grained brown sandstone and gray and olive shale and sandy shale in the upper part. Small faults may cross the line of section. According to R. T. Hazzard (personal communication, 1960), the Gulf Series at the Speck ranch is more than 2,000 feet thick and contains a zone of desmoceratids near the base, a zone of *Pseudaspidoceras* and *Fagesia* spp. about midway, a zone of *Ostrea soleniscus* Meek and gastropods in the upper third, and a zone of *Coilopoceras* sp. in a shale zone at the top.

Smith's (1940, pp. 28–29) measured section 5, east of the Speck ranchhouse, yielded *Inoceramus* sp. at intervals in the lower 250 feet and *Ostrea* sp. in a 40-foot zone about 365 feet from the top. In the same area, about 375 feet above the base of the formation, a black, nodular limestone that weathers very pale orange yielded *Inoceramus* sp. and *Pseudaspidoceras* sp. The brown-weathering sandstone about 850 feet above the base yielded *Gyrodes?* sp.

In the Eagle Mountains, the Chispa Summit Formation crops out in the Eagle Spring and Carpenter Spring areas and in the valley south of Wyche Ridge, where it is largely covered by gravel and alluvium. Near Eagle Spring, more than 1,400 feet is exposed (Smith, 1941, p. 74), including coal seams in black shale. The Chispa Summit is well exposed in Carpenter Canyon, where Taff (1891, pp. 734–735) measured 1,120 feet of brown, fissile, calcareous shale and sandy shale, calcareous flaggy sandstone, and black, fissile shale and sandy shale containing *Inoceramus* sp. Gillerman (1953, p. 33) collected *Coilopoceras* sp., *Romaniceras?* sp., *Ostrea soleniscus* Meek, and *Inoceramus* sp. near Carpenter Spring. Fish teeth and fish scales have also been collected from the shale within a few feet of Carpenter Spring.

The largest exposure of Chispa Summit in the Indio Mountains is along the base of the southern half of Willoughby Ridge and in the valley northeast of the ridge where much of the formation is covered by gravel and alluvium. One small, isolated outcrop (Q.4–15.5) is just west of the north end of Willoughby Ridge in a window in the overlying thrust sheet of the Yucca Formation; another (T.1–17.5) is a short distance west of Green River and just south of the road to Indio Pass.

The Chispa Summit in this general area is thin bedded and consists of calcareous, fissile, yellow to black shale with a bituminous odor, olive to brown flaggy calcareous sandstone, and gray to olive shale with large discoidal septarian concretions. Gypsum permeates much of the shale. There are also distinctive sandstone cylinders of unknown origin, up to 6 inches in diameter and perpendicular to bedding, in the Chispa Summit.

In the Chispa Summit outcrop just east of Willoughby Ridge, *Inoceramus* sp. and *Collignoniceras* aff. *C. chispaense* Adkins were collected; north-northeast (P.8–16.0) near the point where the road leading west to Oxford crosses the main stream channel, *Calycoceras* sp. as float and *Romaniceras* sp. in place were collected at an undetermined height above the base of the formation. The widespread gravel and alluvium that cover much of the formation in this valley preclude measuring the thickness of the strata, but more than 1,000 feet is probably present.

Where several hundred feet of highly deformed, yellow-brown gypsiferous shale and marl are exposed (T.1–17.5) just south of the Indio Pass road, *Inoceramus* sp., *Eucalycoceras underwoodi* Powell, *Vascoceras* sp., *Mantelliceras* sp., *Prinocyclus* sp., and *Collignoniceras* sp. have been collected. The fauna may be correlative with zone 5 of Adkins at Chispa Summit; if so, the age of the Chispa Summit Formation in this small outcrop is late Turonian (Twiss, 1959b, pp. 49–50).

The ammonites from just east of the Speck ranchhouse indicate that the age of the formation in the Devil Ridge area ranges from late Cenomanian to perhaps as young as late Turonian (Adkins, 1933, p. 437). The Chispa Summit exposed along the east flank of the Indio Mountains may also be as young as late Turonian.

The Chispa Summit is paleontologically correlative with the Eagle Ford of central Texas, the Ojinaga of northern Chihuahua, and the Boquillas in the Big Bend area. Its age is late Cenomanian and Turonian. It is possible that the upper part of the Chispa Summit in the Sierra Vieja region may be as young as Campanian (Twiss, 1959b, p. 50).

CENOZOIC ROCKS

There is considerable difference between the eruptive rocks of the Eagle Mountains and those of the Indio Mountains. Although both sequences are sodium-rich rhyolitic and trachytic rocks, the homotaxis, thickness, surface expression, texture, and color are different. In the Indio Mountains there is an alternation of relatively homogeneous fine-grained tuff and microporphyritic welded tuff or trachyte, whereas in the Eagle Mountains the extrusive igneous rocks are volcanic breccia, flow breccia, and rhyolite flows. The two sequences of extrusive igneous rock cannot be directly compared chronologically because they are not in contact at the surface.

The light-colored, fine-grained, microporphyritic intrusive rhyolite of the Devil Ridge area resembles that of the northern Indio Mountains, and both are similar to the rhyolite of the Eagle Mountains.

Basin fill of Tertiary and Quaternary age and terrace gravel, alluvium, and windblown sand almost encircle the highlands of the map area.

INTRUSIVE ROCKS OF DEVIL RIDGE AREA

Quartz latite porphyry.—A sill from 40 to 50 feet thick in the Cox Sandstone on the northeast flank of Texan Mountain extends southeastward several hundred feet into the map area (A-1). The rock is a medium light gray, quartz latite porphyry, with euhedral and anhedral crystals of pinkish-gray and very light gray feldspar up to 1.5 cm in diameter in an aphanitic groundmass. Great numbers of pinkish-gray euhedral crystals have weathered out of the matrix. The quartz latite porphyry is the youngest of the sequence of intrusive rocks of the northern Quitman Mountains (Huffington, 1943, p. 1037, pl. 1); it is seemingly unrelated to the igneous rocks of the Eagle and Indio Mountains.

Rhyolite.—The sill in the Espy Limestone north of Wiggleton tank (E-5, 6) is white and very light gray, compact, fine-grained microporphyritic rhyolite. A sample from the southwesternmost outcrop contains alkalic feldspar spherulites up to 0.5 mm, a few embayed quartz phenocrysts and alkalic feldspar phenocrysts averaging 1.0 mm, and microphenocrysts of euhedral partly resorbed alkalic feldspar laths (Md 0.1 mm) in a cryptocrystalline matrix of alkalic feldspar and quartz. The rock fractures conchoidally.

In the area east of the Speck ranchhouse, dikes and sills of rhyolite have intruded the Yucca, Espy, Eagle Mountains, Buda, and Chispa Summit formations. Sills predominate and have an average thickness of 30 to 40 feet. Magma that formed the dikes probably intruded along faults; the largest dike is about 100 feet wide and is exposed in a series of light-colored outcrops (H-8) aligned slightly north of east in the valley just north of Pagoda Hill. The rock is very pale orange with abundant light brown concretions of iron oxide less than 0.1 mm in diameter derived from the oxidation of iron-bearing minerals. Quartz and alkalic feldspar phenocrysts up to 2.5 mm are enclosed in a fine-grained cryptocrystalline matrix of quartz and alkalic feldspar, which shows rudimentary granophyric and spherulitic texture.

A rhyolite sill about 50 feet thick crops out (G-9) within the Espy Limestone east-northeast of the Speck ranchhouse. The rock is greenish gray with abundant clear quartz and altered biotite phenocrysts averaging 0.7 mm in maximum dimension. Pinkish-gray phenocrysts of albite-oligoclase, many of them altered to yellow and red-brown iron oxide, average about 1.5 mm in maximum diameter. The matrix is a fine-grained mosaic of quartz and alkalic feldspar (Smith, 1940, p. 619). A patina of iron oxide, in places up to 4 mm thick, is characteristic of the rhyolite of this area.

The easternmost outcrop of intrusive igneous rock in the Devil Ridge area is more than 2 miles from the steep cliffs of lower rhyolite on the west flank of the Eagle Mountains, but the rhyolite of the two areas is probably contemporaneous and from the same magma chamber.

Lamprophyre.—Small dikes of dark-colored "trap rock" (Smith, 1940, p. 619) crop out along the road (H.3–8.6) leading to the windmill and tank in Goat Arroyo upstream from the Speck ranchhouse, along the west bank of Rattlesnake Draw (G.9–8.5) near the Buda-Chispa Summit contact, and several hundred feet farther upstream (G.8–8.6) where the same rock has intruded the Buda, either along the fault that runs just west of the draw or along a fracture related to the fault. The rock is various shades of olive gray and weathers readily. It is fine grained and contains equidimensional phenocrysts of calcite (Md 0.5 mm), which probably originated through the alteration of olivine. The rock also contains much secondary iron oxide.

With the exception of faint local baking, the intrusive rocks have had little effect on the country rock. Direct evidence permits dating the rhyolitic intrusive rock of the Devil Ridge area only as younger than Chispa Summit and older than basin fill.

ERUPTIVE ROCKS OF EAGLE MOUNTAINS

The eruptive rocks of the Eagle Mountains compose the interior, highest part of the mountains. The texture of each of the three major mapped units—from oldest to youngest, lower rhyolite, trachyte porphyry, and upper rhyolite—is both horizontally and vertically variable.

The intrusive rocks include rhyolite, microgranite, quartz syenite, basalt and diabase. The small stock is Eagle Peak Syenite.

Aside from the basalt which is included in the rocks shown on the map as diabase, the only basalt (M.7–14.4) known in the Eagle Mountains is exposed on the crest of Wyche Ridge north-northwest of Wyche's concrete-and-rock dam, where a small outcrop of dark gray, fine-grained, compact basalt rests on lower rhyolite. Whether the rock is intrusive or extrusive could not be determined.

Although the age of the eruptive rocks of the Eagle Mountains may be inferred from regional geology to be Oligocene in age (DeFord, 1958), no vertebrate fossils have been recovered.

Lower rhyolite.—The "lower rhyolite" is a sequence of sedimentary rock, extrusive and intrusive rhyolite, volcanic breccia, flow breccia, and tuff that ranges in thickness from several hundred to more than a thousand feet. This sequence was deposited on an uneven surface of Cretaceous rock where relief was as much as 500 feet. Formations of Comanche and Gulf age are overlain unconformably by the lower rhyolite.

The lower rhyolite is widely exposed in the Spar Valley and the Carpenter Spring area, where it is difficult to distinguish between extrusive and intrusive rock. From the Rhyolite fault north, the lower rhyolite is more extensive and thicker than to the southeast, and steep-walled canyons with high gradients, such as Black Rock, Horse, and Goat Canyons, are incised in it. East of Broad Canyon along the south flank of the mountains, the lower rhyolite does not crop out. Along the west flank of the mountains and in the vicinity of Black Butte, the lower rhyolite is exposed in precipitous cliffs and probably reaches a thickness of at least 800 feet, although much of it is covered by colluvium.

Near the large solution caves in the lower rhyolite on the west flank of the Eagles just above Indian Springs, a volcanic breccia with a pale yellowish-green matrix that encloses grayish-red volcanic rock fragments (Md 2.5 cm) grades upward to a volcanic breccia with a white matrix that contains smaller fragments of volcanic rock, chert, and quartzite (Md 3 mm). Just beneath the overlying trachyte porphyry there is a pale red-purple rhyolite with microphenocrysts of quartz and with pronounced flow structure. This rock weathers to fragments that resemble silicified wood. At MS 13, there is a 6-foot zone between the lower rhyolite and the overlying trachyte porphyry that consists of angular blocks of both types of rock. To an observer at some distance, however, the contact is sharp and distinct.

At MS 15 on the northwest flank of Panther Peak, more than 1,000 feet of the lower rhyolite is exposed. At the base, a thin-bedded lithic tuff composed of grains of volcanic rock dips 14° N. The remainder of the section is largely volcanic breccia, spherulitic rhyolite, and rhyolite. Much of the volcanic breccia is composed of red volcanic rock fragments embedded in a green, aphanitic matrix. Beginning about 417 feet above the base of MS 15, there is an 8-foot zone of spherulitic rhyolite in which white spherulites of alkalic feldspar (Md 2.0 mm) are enclosed in a pale red-purple aphanitic matrix of quartz and alkalic feldspar. The uppermost layer of rhyolite at MS 15 is grayish pink, slightly spherulitic, and has flow structure similar to that of the upper part of the lower rhyolite above Indian Springs.

At TC Peak less than a mile north of Panther Peak, much of the lower rhyolite is a thick-bedded, volcanic breccia that contains angular and round fragments of fine-grained quartzite, spherulitic rhyolite, and limestone up to 5 feet in diameter (Gillerman, 1953, p. 35; Smith, 1941, p. 74). The volcanic breccia forms the resistant cap of the peak as well as about half of the section below the cap. Beneath the volcanic breccia there is a light greenish-gray sandy tuff.

On the southwest flank of the mountains, about 300 feet of rock that is probably near the base of the lower rhyolite is well exposed in a draw near where it is crossed (L.9–9.4) by the pasture road that leads southwest from the Hayter ranchhouse. Downstream from the road crossing, there is an outcrop of *Orbitolina*-bearing Bluff limestone that strikes N. 15° W. and dips 25° NE.; the limestone concordantly underlies the lower rhyolite. The outcrop of lower rhyolite is a variegated sequence of sandy and lithic tuff, volcanic breccia, and rhyolite. The breccia consists of quartzite, limestone, and volcanic rock fragments that range up to 6 feet in diameter. The rock of this section is generally light colored and ranges from thin bedded to massive. Typical of the rocks that compose the lower part of the lower rhyolite on the west and southwest flanks of the Eagles is the light greenish-gray tuff or volcanic breccia that contains irregular fragments of a grayish-green serpentine-like mineral.

Much of the rock that composes the lower part of the lower rhyolite is well stratified and probably comprises lacustrine or fluvial deposits into which volcanic debris was incorporated.

Gillerman (1953, p. 35), who was particularly interested in fluorspar deposits in the rocks of lower rhyolite in the Spar Valley, described the rocks as flows of porphyritic rhyolite containing quartz and sericitized orthoclase phenocrysts and occasional small granophyric intergrowths of quartz and orthoclase and as flow breccias containing fragments of rhyolite and sedimentary rocks. The flows are more andesitic upward and are composed of phenocrysts of albitized plagioclase and some orthoclase plus rock fragments in a groundmass of quartz and feldspar.

A possible vent (M.4–14.0) lies near the northwest end of Wyche Ridge at the summit of a small ridge that leads a few degrees east of south from the outcrop of Espy Limestone at the sharp bend in the stream channel near the mouth of Wind Canyon. The lower part of the ridge is composed of hard, compact, trachytic, fine-grained tuff whose color, between grayish orange and very pale orange, is controlled by intergranular iron oxide. The upper part of the hill is characterized by an assortment of rocks such as silicified spherulitic rhyolite, volcanic breccia, silicified tuff, basalt, and silicified limestone. A roughly circular, vertical contact seemingly exists between rocks of the upper and lower parts of the hill.

Trachyte porphyry.—The outcrop of "trachyte porphyry" along the east flank of the Eagles is narrow, and this rock is missing or hidden by younger rock along the south flank of the mountains. It thickens to the west, however, as does the lower rhyolite; at MS 13 (J.6–9.4) there are 743 feet of trachyte porphyry. The trachyte porphyry caps Black Butte, covers the area on the west flank of the mountains known as the Roof Garden (J-9), forms the upper part of Black Peak (J-10), and constitutes several small outliers in the Eagle Spring area. Beginning at the mouth of Snowline Canyon, trachyte porphyry extends along the southwest flank of the mountains as far north as Frenchman Canyon.

The lower rhyolite and the upper rhyolite are in contact near Eagle Rock and just north of Frenchman Canyon. The trachyte porphyry may have been eroded or it may never have been present in the area.

To the east the lower rhyolite and trachyte porphyry grade vertically into one another; the gradation suggests continuous eruption. On the other hand, at Black Butte there is a discordance between the lower rhyolite and overlying trachyte porphyry. It is possible that the trachyte porphyry on the west was never continuous with that on the east; indeed, they may not be contemporaneous.

Along the west flank of the Eagles, the lower rhyolite-trachyte porphyry boundary is very distinct. The light-colored, rounded weathered surface of the lower rhyolite is in sharp contrast with the dark-colored angular blocks of the trachyte porphyry. Near the head of Spar Valley, the lower rhyolite grades upward into the trachyte porphyry; along the east flank of the mountains south of the Eagle Mountains ranchhouse, the contact between the two is distinct. There, the color of the uppermost part of the lower rhyolite is between grayish pink and pale red; the rock is characterized by pronounced flow structure and microphenocrysts of quartz and feldspar. This is in strong contrast with the hard, compact grayish-red trachyte porphyry with euhedral to anhedral, very pale orange phenocrysts of alkalic feldspar.

Just south of Wind Canyon, the trachyte porphyry either intrudes or intertongues with the lower rhyolite. East along the ridge that forms the south wall of Wind Canyon, beginning just south of the Eagle Mountains ranch, the sequence of west- or southwest-dipping rock is upper rhyolite, trachyte porphyry, lower rhyolite, and trachyte porphyry. The same sequence holds for the ridge parallel to and just south of this one. The outcrops of trachyte porphyry within the lower rhyolite are small and are not shown on the map.

The color of the trachyte porphyry in this area is light gray, medium light gray, light brownish gray, pale yellowish brown, or grayish red. Compositionally and texturally the rock is less varied; it consists of euhedral to anhedral phenocrysts of white alkalic feldspar ranging up to 9 mm (Md 4 mm) in an aphanitic, darker matrix. The rock is compact; it forms rounded hills and relatively smooth slopes. The trachyte porphyry near the upper reaches of Frenchman Canyon, as well as that just north of the booster mill on the south side of the canyon, ranges from light gray to medium gray. Composition and texture are similar to that north and south of Wind Canyon. Behind Hayter's house and southeast along the southwest flank of the mountains and at Eagle Spring, Black Peak, Roof Garden, and Black Butte, the trachyte porphyry is grayish red or pale red or pale brown, and the feldspar phenocrysts are smaller (Md 3 mm) and less distinct. The rock is hard and compact and weathers to angular blocks.

The trachyte porphyry at MS 13 is typical of that in the western part of the map area. Euhedral and subhedral phenocrysts of anorthoclase that range up to 15 mm (Md 2.0 mm) are enclosed in a fine-grained, granophyric matrix of alkalic feldspar and interstitial quartz. Zircon and apatite are accessory minerals. The rock is brittle, intensely fractured, and highly weathered. The red-brown color is derived from the finely disseminated dust of orange, red, and black metallic iron oxide that, together with larger fragments of these same materials, composes 25 to 30 percent of the rock. The shape of some of the grains of opaque minerals suggests that they were originally mafic minerals that have been altered to iron oxide.

Although interstitial quartz composes as much as 10 to 15 percent of the rock at MS 13, elsewhere quartz is less abundant (Gillerman, 1953, p. 36). The rock over-all is a trachyte porphyry, but locally it may be a quartz trachyte porphyry or a rhyolite porphyry.

Gillerman (1953, pp. 36–37) suggested that some of the outliers of trachyte porphyry in the Eagle Spring area may be intrusive.

Upper rhyolite.—The precipitous, bare, light-colored slopes of Eagle Bluff rise nearly 2,000 feet above the basin fill on the east flank of the Eagle Mountains. Eagle Bluff and much of the higher parts of the Eagles are composed of varied rhyolitic volcanic rocks shown on the map as "upper rhyolite."

This formation is composed of rhyolite, volcanic breccia, and flow breccia and includes the areally restricted basal conglomerate of Gillerman's "upper rhyolitic series." The roughly circular outcrop of upper rhyolite surrounds the stock of Eagle Peak Syenite. At Eagle Bluff, the upper rhyolite is 1,500 to 2,000 feet thick; it thins northward and westward.

The upper rhyolite, excluding the small outcrops of the basal conglomerate between Siphon and Wind Canyons, consists of two types of rocks: a rhyolite and an overlying volcanic breccia. The volcanic breccia is best exposed at Eagle Bluff on the east flank of the mountains; the less conspicuous underlying rhyolite is widely exposed in the central part of the Eagles. The rhyolite is compact and aphanitic with microphenocrysts of quartz and light-colored feldspar in a much darker aphanitic groundmass. The color ranges from light gray to medium dark gray to dark greenish gray to pale blue. The rock is brittle and intensely fractured; it weathers to smooth-surfaced, angular blocks.

In Cottonwood Canyon, this lower part of the upper rhyolite is brownish gray to medium gray and shows flow structure marked by elongate silica-filled vesicles. Its angular, blocky weathering habit is in contrast to the smooth, weathered surface of the overlying volcanic breccia of the upper part of the formation. In the lower unit there is a change in dip toward the mouth of Cottonwood Canyon, where apparent dip of the rhyolite is about 20° S. It may be the result of subsidence during or following eruption, or it may be the result of post-volcanism folding.

At Rocky Ridge, the lower part of the upper rhyolite caps the highest point and is a medium light gray, compact, brittle, spherulitic rhyolite. The spherulites are white feldspar and range up to 5 mm (Md 1.25 mm). The rock also contains microphenocrysts of quartz and feldspar.

According to Gillerman (1953, p. 37), the upper rhyolite adjacent to the syenite stock is andesitic and contains quartz, large oligoclase phenocrysts (some albitized), clusters of secondary aegerite augite, and grains of augite, piteonite, and magnetite in a groundmass of quartz and oligoclase. He suggested that soda-rich solutions caused extensive albitization. Farther away from the stock, albitization occurred only along fractures.

The volcanic breccia that composes the upper part of the upper rhyolite forms the upper and steeper part of Eagle Bluff as well as much of the high ridges and peaks in the vicinity of High mill (M-12). At Eagle Bluff, erosion has carved this rock into smooth-surfaced spires and pinnacles with broad, rounded silhouettes. The aphanitic matrix ranges from white to light gray to very pale orange and contains microphenocrysts of quartz as well as angular fragments of volcanic rock, quartzite, and limestone that range from sand size to several inches in diameter. Near the top of Eagle Bluff is a zone of undetermined thickness of very pale orange tuffaceous rhyolite that is almost free of breccia. It is characterized by intense liesegang banding.

The lowest part of the volcanic breccia as well as the underlying compact gray rhyolite are exposed at the mouth of Cottonwood Canyon. The breccia has poorly developed bedding and is very poorly sorted. Angular fragments of sandstone and yucca-like conglomerate range up to 2 feet in diameter (Md 1 in.).

The highest and steepest part of Eagle Bluff has a dike-like form. Rock near the base of this highest part of the bluff, however, has pronounced horizontal flow structure. Just west of Cottonwood Canyon and between two of the large anomalous limestone blocks of the Bluff Formation, the upper rhyolite has the gross outline of a volcanic cone that has been breached to the south. The shape is especially suggestive of a cone when viewed from the south or from the air, but there is no evidence on the ground to indicate such a feature.

Within the upper rhyolite on the flanks of Eagle Bluff, there are outcrops that have been identified as Bluff Formation, Cox Sandstone, and Espy Limestone. Neither the identity of these rocks nor their mode of emplacement within the upper rhyolite is certain. The smaller blocks may be xenoliths.

Lower rhyolite sills.—On the north and east flank of the mountains near the contact of the lower rhyolite volcanic rock sequence and the Cretaceous and Permian sedimentary rocks, sills of orange-weathering lower rhyolite have intruded the Cox Sandstone in Lone Hill (H,J-12), in Espy Ridge (J,K-13), and in the ridge just north of Spar Valley (M-14,15). Because slopes on the Cox are characteristically mantled with colluvium, the sills are not well exposed. However, discontinuous bands of orange-weathering rhyolite are in reasonably sharp contrast with the gray- and brown-weathering sandstone of the Cox. Not all these sills were mapped; the width of some shown on the map is necessarily exaggerated. The well-exposed sills of lower rhyolite that intrude the gray Espy Limestone along Wyche Ridge are in strong color contrast to the country rock. Also well exposed is a 25-foot sill of lower rhyolite that intrudes the Benevides Formation at the locality of MS 8 (M.6–14.3).

These sills range in thickness from a few feet to several hundreds of feet; they show well-developed liesegang bands.

Sills and irregular bodies of the lower rhyolite have also intruded the Hueco and Yucca formations in the Eagle Spring area and the Chispa Summit Formation in the Carpenter Spring area; in the vicinity of the Spar Valley fluorspar workings and in the area of the Lucky Strike prospect, the lower rhyolite and rocks of Cretaceous age are intimately associated. The ridge of Finlay Limestone south-southwest of Black Butte near JUDGE triangulation station is cut by dikes of lower rhyolite 2 to 3 feet wide.

Clearly all these intrusive bodies of lower rhyolite were emplaced at about the time the lower rhyolite lava was extruded. Perhaps the localization of the intrusive rhyolite along the north and east flank of the Eagles is an indication that the magma gained access to the surface in this area through one or more vents or fissures. No vents were identified, but the Eagle Peak Syenite stock may be emplaced within a major vent. Although locally variable, the rhyolite is characteristically light colored (white, gray, very pale orange), fine grained, and in places is microporphyritic and spherulitic. Patinas of iron oxide are common on weathered surfaces; irregular patches of iron oxide scattered throughout give the rock a spotted appearance on a fresh surface. Some of the rhyolite is distinctly laminated.

In the northeast-facing scarp of Cox Sandstone that overlooks the west flank of the Precambrian outcrop, a 20- to 30-foot sill (K.8–13.6) that crops out for several hundred feet is composed of altered zoned laths of white feldspar up to 1 cm long in a light olive-gray, fine-grained matrix. Although shown on the map as a sill of lower rhyolite, this rock is distinctly different from the lower rhyolite that composes the other sills.

Eagle Peak Syenite.—Gillerman (1953, p. 38) proposed the name "Eagle Peak Syenite" for the compact rock of a small stock that makes up the interior and highest part of the Eagle Mountains. Small apophyses of the Eagle Peak Syenite crop out east of the stock in a small canyon near East mill (M-13) and just north of the Marine ranchhouse

(L-13), where the syenite caps a nearly circular, low rounded hill. North of the main stock, small intrusive bodies of the syenite crop out within the lower rhyolite, the trachyte porphyry, and the upper rhyolite in the general vicinity of the upper reaches of Frenchman Canyon (K,L-11,12). Vertical contact between the Eagle Peak Syenite and the upper rhyolite is well established at the east of the crescent-shaped stock, but in places toward the west end the syenite appears to be concordant with and underlain by extrusive upper rhyolite (Gillerman, 1953, p. 38). The syenite may be a sill between the extruded layers of upper rhyolite. The syenite (K,L-9) just west of Middle Mountain is in vertical contact with the lower rhyolite through most of the outcrop, but the two eastward extensions of the syenite (sec. C-C′) look like sills in the lower rhyolite.

The color of most of the Eagle Peak Syenite is pale brown—pale yellowish brown; at the east end of the stock near the contact with the upper rhyolite, it is medium dark gray. Samples from this area invariably have a discolored zone extending as much as half an inch inward from the weathered surface. Weathered surfaces are various subdued shades of brown and orange. Erosion has carved V-shaped valleys and ridges with relatively steep, unbroken slopes in the syenite, but the effects of erosion on the upper rhyolite and the Eagle Peak Syenite are not different enough to distinguish these formations.

The syenite is composed of phenocrysts of subhedral alkalic feldspar and minor amounts of anhedral iron olivine and subhedral plagioclase in a fine-grained orthophyric matrix of quartz, alkalic feldspar, and an unidentified mafic mineral. Apatite and zircon are accessory minerals. Much of the olivine has been altered to iron oxide—hematite, limonite, and magnetite. The few grains of plagioclase are commonly armored with alkalic feldspar; the phenocrysts of alkalic feldspar are commonly armored or patchily zoned with alkalic feldspar of lower index of refraction. The rock has a granophyric texture. Locally, the Eagle Peak Syenite is a microgranite; quartz constitutes as much as 15 to 20 percent of the rock. The terms "porphyritic" and "porphyry" are also applicable because phenocrysts of alkalic feldspar are up to 6 mm long and constitute as much as 25 percent of the rock.

Diabase dikes.—In several areas within the Eagle Mountains, near-vertical or vertical dikes composed of a dark greenish-gray, fine-grained rock are in sharp contrast to light-colored sedimentary and igneous country rock. These dark rocks do not have everywhere the same composition or texture, but they are classified generally as diabase.

On the south flank of Lone Hill (J.2–12.3), diabase has intruded along the Lone Hill fault and is exposed for several hundred feet in an outcrop about 100 feet wide. The outer part of this dike is a dark gray basalt porphyry composed largely of laths of andesine and labradorite in a cryptocrystalline matrix. The rock has a subtrachytic texture. The inner part is a coarser-grained, greenish-gray quartz diabase of similar composition but with a granophyric texture.

At Rocky Ridge (M-11) a dike of greenish-gray and light brownish-gray diabase cuts the Bluff Formation as well as the upper rhyolite. The dike is only about 4 feet wide but crops out for a distance of over 3,000 feet.

At the mouth of Snowline Canyon (M.8–10.4), a little more than a mile west-southwest of Rocky Ridge, the road crosses a coarser-grained quartz diabase dike more than 50 feet wide that has intruded the lower rhyolite and trachyte porphyry (Gillerman, 1953, p. 39). What is presumably the same rock has also intruded the lower rhyolite and the Cox Sandstone a few hundred feet to the southwest. The diabase there, however, is finer grained than that near the road; the dike has been offset by northwest-trending faults.

At about the midpoint of Wyche Ridge (M,N-14), a southwest-trending dike of greenish-black basalt porphyry has intruded the Espy, Eagle Mountains, and Buda Formations. Because the dike is aligned with nearby normal faults, it may have intruded along a parallel fracture. A dike of altered light gray and greenish-gray, fine- to coarse-grained intrusive breccia also cuts the rocks of Wyche Ridge about 4,000 feet northwest of the dike of basalt porphyry just described. The outcrop is too small to show on the map.

Late rhyolite dikes.—Because the Wind Canyon fault offsets the Eagle Peak Syenite, the faulting must be younger than the emplacement of the syenite. Presumably at the same time, movement also took place along the other east-west faults, such as the Eagle Spring, Lone Hill, and Rhyolite faults. Perhaps, therefore, the rhyolite that intruded along the Eagle Spring and Lone Hill faults as well as similar rock north of Eagle Spring and Siphon Canyon are products of the latest igneous activity in the area.

Yet it seems probable that the east-west faults have had two periods of movement, the first during the Laramide tectonism and the second after the intrusion of the syenite. If so, the emplacement of the rhyolite along the east-west faults could have happened at any time during the period of igneous activity.

The relation of an outcrop of trachyte porphyry to the rhyolite that intruded along the Eagle Spring fault south-southeast of Eagle Spring is unclear. If the trachyte porphyry overlies the rhyolite and the fault along which it is intruded, the intrusion as well as the faulting is older than the trachyte porphyry.

The southernmost of the two long, late rhyolite dikes north of Siphon Canyon cuts the trachyte porphyry. If this intrusion is contemporaneous with that at Eagle Spring, all the dikes are younger than the trachyte porphyry. Hand specimens, however, from the dikes in the two localities are not strikingly similar, although both rocks are light-colored fine-grained rhyolite. Nevertheless, the general east-west trend of both sets of dikes suggests that they may be contemporaneous.

The rocks mapped as late rhyolite sills closely resemble those shown as lower rhyolite sills. There is no more variation in color, texture, and weathering habit between the rocks of these two groups than there is between samples of the same group from different localities.

The color of the rhyolite ranges from white to very pale orange, and the rock is fine grained and compact. Microphenocrysts of alkalic feldspar are common; no spherulites were detected. Northwest of Eagle Spring, grayish-olive pitchstone is associated with the rhyolite along the Eagle Spring fault.

ERUPTIVE ROCKS OF INDIO MOUNTAINS

The northern Indio Mountains lack extrusive igneous rocks; the southern Indios lack intrusive igneous rocks. The Cretaceous rocks of the northern Indios have been intruded by dikes and sills of Tertiary rhyolite. The Cretaceous rocks in the southern Indio Mountains were once partly or, more probably, totally covered by Tertiary welded tuff, tuff, rhyolite, basalt, sandstone, and conglomerate.

The intrusive igneous rocks of the northern Indios have been mapped as rhyolite dikes and sills under the symbol "Tr" because the rocks are not lithologically distinctive, and they are difficult to correlate with igneous rocks of nearby areas. They do not resemble the extrusive igneous rock of the southern Indio Mountains but are more like the rhyolite of the Eagle Mountains in color, texture, and composition.

The Garren Group of Hay-Roe (1957, 1958) and Twiss (1959a, 1959b) has been extended westward into the southern Indio Mountains because (1) the upper part of the group can be traced on the surface from the Van Horn Mountains area westward across Green River into the Indio Mountains, and (2) there is marked lithologic similarity between the Pantera Trachyte in the Wylie, Van Horn, and southern Indio Mountains.

The lava flows, nuée ardentes, and ash falls that deposited the volcanic material in the southern Indio Mountains probably extended some distance westward. Extrusive igneous rocks in the Cieneguilla area north of the Rio Grande are similar to those in the southern Indio Mountains.

Rocks of the Garren Group crop out in three areas in the southern Indio Mountains: along and just west of Green River, in the vicinity of Flat Top (U-15), and in Lost Valley (W,X-15). The group is a sequence of alternating nonresistant tuff and ledge-forming welded tuff or quartz trachyte. A tuff forms the basal unit. The Pantera Trachyte is the middle resistant unit; the three units below the Pantera compose the Hogeye Tuff, and the two units above are mapped simply as tuff (Ttu) and trachyte (Ttr). The best exposures of the Garren Group are in the vicinity of MS 4 (U.4–17.0).

Hogeye Tuff.—In the southern Indio Mountains the Hogeye Tuff is composed of three unnamed members: a lower tuff (Thtl), a middle trachyte (Thtr), and an upper tuff (Thtu).

The lower tuff member (Thtl) is present only in the vicinity of MS 4 (U.4–17.0) where it overlies the Yucca Formation. Although the lower tuff is covered at MS 4, its thickness there is about 32 feet. A short distance north of the nearby road that leads generally southeast to Green River, a few feet of the lower tuff are exposed. There it is a white, highly calcareous tuff with fragments of quartz and volcanic rock, and a very light gray, poorly sorted, limestone breccia. The breccia is composed of angular and rounded fragments of very finely crystalline limestone that range up to 2 inches in diameter (Md 0.5 in.) The tuff, as well as the breccia, is brittle and exhibits conchoidal fracture. A few feet of the lower tuff may be present from place to place in the Flat Top area and in Lost Valley; if so, the tuff is covered.

The trachyte member (Thtr) of the Hogeye is well exposed at MS 4, where it is about 170 feet thick and forms a prominent ledge. The trachyte dips 17° E. and extends about 4,500 feet along strike. About a mile and a quarter north of MS 4 there are two small isolated outcrops (T.6–17.3) of the trachyte member. The trachyte member also composes the roughly circular outcrop (X-15) of igneous rock at Lost Valley and rests on tilted strata of the Cox through the Espy formation. The trachyte member is more than 250 feet thick at the large outcrop (X.2–15.3) just north of the mouth of Eagle Draw. To the north in the vicinity of Flat Top, immediately northwest of the large stock tank (U.5–15.2) that is west of the north end of the mountain, the trachyte member overlies the Yucca Formation. It is well exposed along the draw that leads west from the tank; a smaller outcrop (U.3–14.3) lies just north of the point at which this draw joins a larger one. In a still smaller outcrop, trachyte overlies south-dipping beds of the Yucca Formation about 3,500 feet south of the largest outcrop of the trachyte member and about 3,000 feet west of the road.

The characteristic color of the trachyte is pale red, but in places parts of it are also pinkish gray, grayish orange pink, light brown, and moderate brown. The rock is compact and displays conchoidal fracture. In places, elongate, subparallel, generally weathered amygdules and rock fragments give the rock some degree of flow structure. The trachyte consists of crystals and crystal fragments of anorthoclase and some quartz (Md 0.3–0.4 mm) and fragments of sedimentary and igneous rock that range up to 7 mm in diameter enclosed in a red-brown iron-oxide-stained matrix that in places is fine grained and in other places is partly devitrified glass and glass shards that are or are not welded. In most places, sufficient quartz is present as fragments or as an interstitial component of the matrix to classify the rock as a quartz trachyte or a rhyolite. Much of the rock is a quartz trachyte welded tuff in which elongate, poorly devitrified glass shards are clearly bent around the crystals and rock fragments. Some of the rock is permeated with thin, elongate amygdules of tridymite. Other secondary minerals are microcrystalline quartz and calcite. Accessory minerals are apatite, zircon, and a black, metallic opaque mineral, probably magnetite.

At many outcrops, the typical red trachyte is underlain by 2 to 3 feet of a dark gray, compact rock with a glassy luster. It is a welded or vitric tuff with both crystal and lithic fragments in a matrix ("n" less than 1.537) of glass shards that average 0.25 mm in length. Some of the lithic fragments are 15 mm or more in length. This rock probably is the chilled base of a flow. At Lost Valley just east of the mouth of Eagle Draw, a fine-grained compact, greenish-black basalt crops out (X.2–15.4) on the upper surface of a low ridge of trachyte. It is not known whether this is an extrusive or an intrusive rock.

About a mile west of Green River, the upper member (Thtu) of the Hogeye Tuff is poorly exposed (T,U-17) for almost 3 miles in a narrow north-trending outcrop that is protected by the overlying, resistant, east-dipping Pantera Trachyte. At MS 4 (U.4–17.0), near the south end of this outcrop, this tuff member is about 25 feet thick; it is not present at Lost Valley. To the north in several scattered, poorly exposed outcrops west and northwest of Flat Top, it is considerably thinner than at MS 4, and the color is light gray, light greenish gray, and yellowish gray. The grains range in size from silt to fine-grained sand, and the rock is characteristically friable. Some of it is finely laminated, whereas other parts are massive. About 160 feet above the base of the upper tuff member at MS 4 there is a yellowish-gray tuff that is friable beneath a firm weathered crust; the rock is composed of spheres of calcite enclosed in a glass matrix that are up to 0.5 mm in diameter.

The upper part of the upper member of the Hogeye Tuff is well exposed (T.2–17.5) at the extreme north end of the outcrop belt about a mile west of Green River and half a mile south of the Indio Pass road. There, 50 to 75 feet of alternating ledge-forming and less resistant vitric and crystal tuff rest on the Chispa Summit Formation. The color of the tuff ranges from medium light gray to grayish orange pink to pale pink; the rock is fine grained and friable. The upper resistant tuff bed contains spherical calcareous concretions up to 2 inches in diameter; a lower zone of yellowish-gray tuff contains "cylinders" that average 1 inch in diameter and 2 inches in length and are perpendicular to bedding.

The upper member of the Hogeye Tuff has yielded fossil bones of vertebrate animals, including teeth of *Mesohippus* and an oreodont tooth. According to J. A. Wilson (personal communication, 1962), the fauna indicates a Chadronian or late Eocene—early Oligocene age for the tuff. The fauna as well as the tuff are correlative with those at Ash Springs (Bridges, 1958, pp. 35–36).

Pantera Trachyte.—The Pantera Trachyte is a resistant, characteristically pale red or grayish-red, ledge-forming rock. From the north end of the outcrop belt about a mile west of Green River, a west-facing hogback capped by Pantera (T,U-17) extends south almost 3 miles. In the vicinity of Flat Top there are several low-lying resistant ledges (U, V-15) of the Pantera Trachyte.

The Pantera is 45 feet thick at MS 4 (U.4–17.0), including 6 feet of welded crystal tuff at the base that ranges in color from black to light gray. At High Lonesome in the Van Horn Mountains, about 7 miles to the northeast, the Pantera is about 450 feet thick (Twiss, 1959a); the westward thinning indicates a source to the east. In the Wylie Mountains farther east, the Pantera is the most widespread extrusive rock and thickens westward to a maximum of perhaps 350 feet (Hay-Roe, 1957).

The main part of the Pantera is a compact rock that displays subconchoidal to conchoidal fracture. Rock fragments and crystals and crystal fragments of anorthoclase and some quartz and plagioclase that range up to 3.0 mm in diameter (Md 0.2 mm) are enclosed in a matrix of partly devitrified glass and glass shards that are stained with red iron oxide. The rock has pronounced microeutaxitic texture and is classified as a welded trachytic crystal tuff. The flow structure is not evident in hand specimen. Tridymite is a common secondary mineral that filled or lined cavities. Other accessory minerals are zircon, apatite, and a black metallic mineral, probably magnetite. The pale red to grayish-red color of the upper part of the Pantera is in strong contrast with the varied shades of gray as well as the black color of the lower part of the formation. Microscopically, texture and composition are almost identical, except that the glass shard matrix of the lower part is not stained by red iron oxide. The lower part is less compact. In places, the top of the lower part of the Pantera is black and has a vitreous luster. It, too, is a welded trachytic crystal tuff, but some samples show vague perlitic fractures. Where this black welded tuff contains abundant crystal fragments, it is granular and crumbly; where it has few fragments and is largely glass shards, it is compact and weathers to a smooth surface. In a few places, gray or black well-bedded tuff, probably welded, 1 to 2 feet thick lies above the pale red to grayish-red welded tuff of the upper part of the Pantera. Northwest of Flat Top, a north-trending fence crosses a light greenish-gray friable tuff several feet thick that seemingly lies within the upper part of the Pantera.

Tuff (Ttu) *and trachyte* (Ttr).—The uppermost tuff unit (Ttu) of the igneous rock sequence of the southern Indio Mountains overlies the Pantera Trachyte and at MS 4 is about 170 feet thick. Included within the tuff (Ttu) is a zone of olivine basalt. The tuff (Ttu) is overlain by a resistant trachyte (Ttr), which is the youngest igneous rock of the southern Indios. At MS 3 (V.6–17.2), about 2 miles south of MS 4, a partial section of the tuff is about 525 feet thick, and the thickness of an incomplete section of the tuff at MS 2 at Flat Top to the west is about 305 feet. The tuff thickens south and west because there a tongue of the lowest part of the trachyte wedges out and is replaced by tuff.

At MS 4 only about the lower 18 feet of the tuff are exposed; it is yellowish gray to light olive gray, friable, and weathered surfaces are smooth and rounded. It is a crystal tuff composed of crystals and crystal fragments of anorthoclase and plagioclase, ranging in size up to 2.2 mm (Md 0.3 mm), set in a matrix of partly devitrified glass shards. The rock contains a trace of zircon, about 1 percent of apatite, and 2 to 3 percent of a black, metallic mineral. About 2,000 feet north of MS 4, the upper 40 to 50 feet of the tuff is exposed; its color is distinct, ranging from grayish orange pink (10R8/2–5YR7/2) to moderate orange pink (10R6/4) to pale pink. It is fine grained, thin to thick bedded to massive, and moderately hard. The calcareous, grayish-orange-pink tuff that composes the lower part of the outcrop yielded several specimens of fossil snails of the genus *Humboltiana.*

At MS 3, within a partly covered zone that extends from 231 to 400 feet above the base of the section, compact, dark gray basalt and a scoriaceous, brittle, grayish-red-purple basalt crop out. This same zone underlies the road northwest of Flat Top and is well exposed in a small draw (U.2–15.3) east of the road where a "baked zone" of light red crystal tuff underlies the basalt. This zone of dark gray olivine basalt, along with the brightly colored baked zone, crops out along the west face of Flat Top. The zone is best exposed just north of the water gap at the south end of Flat Top. There the thickness is 10 to 40 feet, and the basalt is underlain by a baked zone. The top of the basalt holds a constant stratigraphic position along strike; therefore, the change in thickness along strike is the result of the irregular surface over which the basalt flowed.

The yellowish and light gray, fine-grained, friable tuff of the lower part of the section at MS 2 and MS 3 resembles that at MS 4. The upper zone of light-colored tuff that yielded the snails near MS 4 is not exposed at MS 3. At MS 2 at Flat Top, rock of this upper part of the section is a lithic or crystal tuff and much less homogeneous than at MS 4. In fact, part of the rock is a tuff breccia.

Quartz trachyte (Ttr) is present over much of the area that extends about a mile west of Green River and about 3 miles south of the Indio Pass road. The rock is poorly exposed, however, because of a cover of gravel (QTg). To the west the trachyte caps Flat Top, where it is 313 feet thick and well exposed. Two small outliers of the trachyte lie immediately north of the mountain. The section of trachyte at MS 3 is 512 feet thick; the rock is a microporphyritic quartz trachyte with euhedral to anhedral microphenocrysts of anorthoclase and a little quartz that range in size up to 3.0 mm (Md 6.0 mm) set in an aphanitic matrix ("n" less than 1.537). Rock fragments are abundant in some zones. Welded tuff composes part of the unit; much of the rock is eutaxitic. Tridymite and calcite have been deposited in many of the elongate vesicles that give rise to the eutaxitic texture. A black metallic mineral, probably magnetite, is a common accessory mineral. Color of the rock is light brown, pale red purple, pale red, and varied shades of gray. The trachyte is compact and shows conchoidal fracture. It, as well as the underlying tuff (Ttu) and the Pantera Trachyte (Tp), can be traced east across Green River into the Van Horn Mountains (Twiss, 1959a); these rock units provide a sound correlation of the Garren Group between the two ranges.

The trachyte (Ttr) is more than 500 feet thick in the Indio Mountains about a mile west of Green River, whereas at High Lonesome to the northeast in the Van Horn Mountains it is only a little more than 300 feet thick. These dimensions, however, probably reflect not original thickness of the flow or sequence of flows but differential erosion after emplacement.

Rhyolite dikes and sills.—Intrusive rocks in the Indio Mountains are concentrated in the northern Indios in the vicinity of Oxford Springs, where numerous near-vertical dikes of rhyolite are 10 to several hundred feet thick and trend from east-northeast to due east. The rhyolite has also intruded as sills, but they are less numerous than dikes. The majority of the intrusive bodies are aligned roughly parallel to the east-northeast faults. These intrusive rocks cut the Yucca, Bluff, and Cox Formations; contact metamorphism is negligible.

Northeast of Oxford Springs near the axis of Oxford syncline, a sill or small stock of rhyolite crops out (P-15) within the Bluff Formation. It is arcuate in plan, about 3,000 feet long and 700 feet wide. The rock is pale pink—pale red purple to grayish orange pink; it is fine grained, hard, compact, and fractures conchoidally. It contains microphenocrysts of alkalic feldspar in a microcrystalline matrix of quartz, alkalic feldspar, and glass. The parallel alignment of quartz and feldspar lenses 0.1 to 0.2 mm long constitutes microeutaxitic texture.

Southwest toward Oxford Springs, a rhyolite dike (P,Q-14) has intruded the Bluff and Yucca Formations. The intrusive rock ranges in color from very light gray to grayish orange and is similar to the rock in the igneous mass to the northeast. The dike rock, however, has more quartz and biotite and exhibits a rudimentary granophyric texture.

West and southwest of Oxford Springs, dikes of light-colored rhyolite are abundant. Typical of these is the dike crossed by the road that runs north past Norte well to Oxford Draw. At the first road crossing (U.9–13.2), the dike is 10 to 12 feet wide, strikes N. 65° E., and dips 74° SE. It is light gray, hard and compact, but not sufficiently resistant to extend more than a few inches above the surface.

The northwesternmost outcrop of intrusive rhyolite, about 1.6 miles north of Oxford Draw (P-12), is a dike striking almost due east and dipping 72° S. that cuts steeply dipping beds of the Yucca Formation. The color of the rhyolite is between pale red purple and pale pink; the rock is compact and has pronounced conchoidal fracture. Microphenocrysts of quartz and sericitized alkalic feldspar are enclosed in a fine-grained matrix of the same composition. At the west end of the dike, columnar jointing is well developed. The long axes of the columns are near horizontal.

There is a small sill in the Bluff Formation northwest of Oxford Springs that is composed of a yellow-green, severely weathered lamprophyric rock. About 300 feet south of the southwesternmost dike of the northern Indio Mountains (Q-12), a near-vertical dike of hard, compact, basalt porphyry has intruded the Yucca Formation. It is 3 to 4 feet wide and crops out for a distance of about 30 feet in an east-northeast direction.

Because no other rocks of these types were found and because their exposures are very small, they are not shown on the map.

OLDER GRAVEL

In places in the southern Indio Mountains a poorly sorted, well-indurated gravel overlies the volcanic rocks. Along the Indio fault east of Flat Top and on south, there are great mounds of gravel. These hills are remnants of a bed of gravel that was emplaced during movement along the Indio fault.

Southeast of Flat Top and near the mouth of Snake Canyon (U,V-15,16), the hills are rounded and the gravel is poorly exposed; much of it has been removed by erosion. On south, in the vicinity of Campo Bonito, steep-walled draws cut the gravel which is composed largely of round boulders of Tertiary volcanic rock with few boulders of Cretaceous rock. The dip is 5° to 6° S. 55° E.

BOLSON FILL

Fluvial, lacustrine, and aeolian deposits, also the result of erosion in response to the difference in elevation created by late Tertiary normal faulting, almost completely surround the Eagle Mountains and their subsidiary ranges. Probably the "older gravel" and some of the oldest part of the "bolson fill" are contemporaneous and intergradational, although in general, the two formations are related to two different episodes of faulting.

These deposits, which filled the troughs (grabens) created by late Tertiary normal faulting, range widely in grain size and composition. They are generally coarse near the margins of the intermontane basins and fine toward the center. The composition of the coarse material is directly related to the rock that was available for erosion in the nearby mountains. Probably much of the fine material came down the ancestral Rio Grande. Thickness of the bolson deposits, based on the known depths of deep water wells bottomed in the fill, is as great as 1,100 feet in places.

A locality (T.8–12.3) along Arroyo Escudo produced bones of the following animals from the youngest part of the bolson fill beneath the capping terrace gravel: *Equus* sp., *Nannippus?* sp., *Lepus* sp., *Eurecyon* sp., *Geomys bursarius, Camelops* sp., *Platygonus* sp., *Glyptotherium texanus, Testudo* sp. (large), and *Proboscidean* (mastodont). This fauna indicates an early Pleistocene (pre-Illinoian) age for the bolson deposits in which they were found. The deposits may be as old as Nebraskan or as young as Kansan.

TERRACE GRAVEL

There are three principal terrace gravels along Green River, the Rio Grande, and Red Light Draw. Mapped from highest and oldest to lowest and youngest as Qg1, Qg2, and Qg3, these represent successively lower base levels of the Rio Grande drainage system. They are not identified by lithology but by relative position above the present drainage system. Within a mile of the Rio Grande, the upper surfaces of the terrace gravels are at the following elevations above the adjacent flood-plain: Qg3, 20 feet; Qg2, 75 feet; and Qg1, 150 feet. Like the bolson fill, the terrace gravels range widely in grain size and composition. They are a loose to well-indurated mixture of particles ranging from the finest silt to boulders. Because their composition depends on the type of rock available in the mountains, composition may vary more widely geographically within one terrace gravel than it does stratigraphically within one gravel or between successive terrace gravels. Near the Rio Grande, the broad, prominent gravel terrace is the second terrace gravel, or Qg2. The highest terrace gravel, Qg1, is patchily preserved near the margins of the bolsons only. Along the arroyos, the lowest terrace gravel, Qg3, is also sparsely preserved.

The correlation of the terrace gravels of the Rio Grande drainage system with those of the Salt Basin drainage system is based primarily on the assumption that the same conditions that produced the great alluvial fans on the southwest flanks of the mountains, produced those on the northeast flanks.

ALLUVIUM

The flood-plains and stream beds of the present streams other than the Rio Grande were mapped as alluvium, Qal 1. The flood-plain of the Rio Grande is cut some 10 to 12 feet below the flood-plain of many of the tributary streams, and this lower level along the Rio Grande is shown as Qal 2. The stream bed of the Rio Grande and that of the tributaries are substantially at grade. Widespread undifferentiated alluvium covers much of the lower parts of the Devil Ridge area and the lower areas along the northeast and east flanks of the Eagle Mountains.

The material that composes the rock mapped as Qal 1, Qal 2, and Qal ranges from the finest silt in the valley flats and the large flood-plains to large boulders in stream channels within the mountains. The range in composition is just as great and includes the many types of rocks that crop out in the map area.

Cracks in the alluvium about 2½ miles southeast of Hot Wells, immediately west of Red Light mills, and near the head of Green River appeared almost overnight. They range up to 2 miles in length, are several feet wide at the surface, and extend downward an unknown depth. The trend of the cracks is generally north, and they are characterized by short branches that are nearly perpendicular to the main fractures. In places their pattern is polygonal. The origin of the fractures seems to be unrelated to earthquake tremors or to the erosive action of water. Their grossly polygonal pattern in places suggests that they may be large desiccation cracks.

WINDBLOWN SAND

Light brown windblown sand has accumulated north and east of Grayton Lake. East of Grayton its areal extent is well marked by a stand of tall yucca. There the sand is composed largely of angular to rounded, frosted, very fine- to medium-grained quartz as well as feldspar, rock fragments, and grains of caliche. The sand north of Grayton contains a much higher percentage of quartz and the sand grains are distinctly finer grained than those to the east. The sand consists of very fine-grained, subangular to subrounded, frosted quartz grains, and little else. At both accumulations the surface of the sand is only slightly irregular; there is a difference of only a foot or less between adjacent high and low points.

STRUCTURE

STRUCTURAL FEATURES OF DEVIL RIDGE AREA

Devil Ridge fault.—Northeast overthrust movement along the Devil Ridge fault was sufficient to bring the Yucca and Chispa Summit Formations into juxtaposition (sec. A-A′), that is, the oldest Cretaceous strata now overlie the youngest Cretaceous strata. Stratigraphic separation is more than 8,000 feet.

Throughout most of its extent, the trace of the northwest-trending Devil Ridge fault is hidden beneath the alluvium just northeast of Front Ridge; the trace is exposed along the northeast face of Love Hogback as well as along the north-facing scarp east of the Speck ranchhouse. The relatively incompetent rocks of the Chispa Summit are overturned and somewhat crumpled near the fault.

Smith (1940, p. 630) cited an exposure "on Love Hogback 2000 to 2800 feet northwest of the Judge Love Ranch [now Speck ranch] . . ." where the fault dips 54° SW. As about 1,000 feet of Yucca is exposed above the fault in the overriding block and about 1,500 feet of Chispa Summit lies beneath the fault in the overridden block, the stratigraphic separation should be roughly 8,000 feet. Assuming that the fault plane becomes less steep at depth, average angle of dip along the plane might be 25°. A stratigraphic separation of about 8,200 feet and a dip angle of 25° would entail about 19,000 feet of movement along the fault.

The stratigraphic throw of the Devil Ridge fault decreases to the northwest. East of the Speck ranchhouse, the fault trace is largely covered.

Red Hills fault.—The Red Hills fault parallels the Devil Ridge fault, and for the most part the trace lies beneath the alluvium between Devil Ridge and Back Ridge. The Devil Ridge and Red Hills thrust faults divide the major part of the Devil Ridge area into three tectonic elements: (1) the foreland block to the northeast, (2) the Devil Ridge thrust block, and (3) the Back Ridge thrust block to the southwest.

Movement along the Red Hills fault placed the Yucca Formation opposite the Finlay Limestone. This relationship is well exposed in Back Ridge where, in places, the trace of the fault is exposed. The dip of the fault plane, as measured on Back Ridge just south of the water gap (F.3–3.6), is 24° SW. If about 450 feet of Finlay is exposed beneath the fault plane and about 1,500 feet of Yucca is exposed above the fault plane, the stratigraphic separation is about 4,800 feet. If an average angle of dip of 15° is assumed, movement along the fault was about 19,000 feet.

Although the Yucca is in contact with the Finlay in most places where the trace is exposed, near the southeast end of Back Ridge the fault sheared an overturned anticline and placed the Yucca opposite the Cox Sandstone. The overturned anticline has also been cut out by the Red Hills fault just northwest of the water gap in Back Ridge as well as between Back Ridge and Red Hills to the southeast.

Minor thrust faults.—Coincident with the major overthrust movement in the Devil Ridge area in response to a maximum horizontal compressive stress régime, there were also relatively minor structural adjustments. The stratigraphic separation of all these minor thrust faults is probably less than 500 feet; of most of them, less than 50 feet.

The outcrops in the area (H,J-8, 9) that lie east and south of the Speck ranchhouse and west of Horse Canyon (J.0–1.1) are composed of thrust-faulted, folded, and normally faulted beds of the Yucca, Bluff, Cox, Finlay, and Espy formations. The incompetent nature of the Yucca made it yield readily to severe compression: it broke in a series of shingle-like low-angle thrust faults (sec. B-B′), but probably the movement was not great along any of them. That the strata were folded prior to thrusting is indicated by the thrust-fault contact of the Yucca and overlying Bluff in the hill (H. 8–8.2) just north of the north end of Speck Ridge. There, the gray limestone of the Bluff is in sharp contrast to the red siltstone and sandstone of the Yucca; the attitude of the two formations, which are in their normal stratigraphic positions, is markedly different.

The vertical and near-vertical beds of Finlay Limestone (J.3–9.6) that extend northwest from beneath the cover of volcanic rock on the west flank of the Eagles are in thrust-fault contact with limestone strata of the Bluff Formation. At the surface, only the upper, *Orbitolina*-bearing beds of Bluff are present beneath the fault. Although the Bluff at the southeast end of the ridges is parallel with the Finlay, the Bluff and Finlay diverge northwestward. The Bluff underlies the valley to the north and reappears to form the high, rugged, northeast-facing scarp just west of the mouth of Horse Canyon.

An inferred strike-slip fault that trends almost due east between Yucca Mesa and Sand Mountain accounts for the westward displacement of the Cox and Finlay formations in Sand Mountain as compared to the same formations on the southeast. The inferred movement along the fault was left lateral. It is possible that the displacement could have resulted from the folding of the beds southwest of Grayton Lake in a very gently southwest-plunging syncline. North of Love Hogback about 1,400 feet of right-lateral movement of beds along a northwest-trending strike-slip fault (G. 2–8.2) has offset strata of the foreland block. A left-lateral, northeast-trending strike fault (J.7–8.7) is inferred to account for the offset in folds north and west of Black Butte. This fault is only the overridden block; thus, its inferred trace extends from beneath the thrust sheet. South of the water gap, Speck Ridge is offset by a left-lateral strike-slip fault along which there was later vertical or near-vertical movement, north side down after the volcanic rocks were in place. The strike separation of the beds is almost 300 feet. The four strike-slip faults just cited represent preferential movement along one of two potential shear fractures on either side of the direction of the greatest principal stresses, which in this area during the Laramide orogeny was approximately northeast-southwest.

The most prominent folds in the Devil Ridge area are along the line of structure section B-B′. Beginning at the southwest end, beds of the Yucca and Bluff Formations dip about 30° northeast. Because the thick-bedded limestone of the Finlay that composes the west limb of Speck Ridge dips southwest and is overlain by the Cox Sandstone, the section there is overturned to the northeast. It is inferred that immediately northeast of the first outcrop along the line of section B-B′, there is a syncline followed by an anticline overturned to the northeast. Speck Ridge, then, is made up of the faulted limbs of two folds: an overturned anticline to the southwest and a syncline to the northeast.

Along the line of section, the limestone beds of the southwest half of Speck Ridge dip 70° to 82° SW. and are part of the overturned limb of the anticline described earlier. The thick limestone beds of the northeast half of Speck Ridge dip 50° to 75° NE. and are separated from the beds of the southwest half of the ridge by a surface along which there was earlier thrust faulting and later normal faulting. The beds of limestone that compose the northeast half of the ridge were dragged upward during the thrust faulting and now form the steeply dipping southwest limb of a syncline.

Northeast of Speck Ridge along the line of section, the topography is dominated by two prominent, southeast-plunging anticlines; the outcrops are composed largely of Finlay Limestone and rise several hundred feet above the surrounding terrain. The southwestern anticline is asymmetrical to the northeast; the other, asymmetrical to the southwest. The folds have an average plunge of about 20°; their steep limbs are vertical or near vertical. Between these two southeastward-plunging anticlines, a sharp syncline in Espy Limestone plunges southeastward and is asymmetrical to the northeast.

Of special interest is the sharp symmetrical syncline exposed on the northwest flank of Black Butte where the converging limbs of massive limestone of the Espy make an angle of about 100°. Presumably this syncline is the same as the one to the northwest between Speck Ridge and the anticline immediately to the northeast.

South of the water gap that cuts Speck Ridge, the steeply northeast-dipping beds of limestone of the northeast half of the ridge continue southeastward until they are covered by alluvium. A strike-slip fault offsets them to the east about midway of the ridge. The limestone beds of the Finlay that make up the southwestern half of the ridge dip steeply southwest or are vertical so far southeast as the strike-slip fault. Immediately beyond that point, the attitude of the thick beds of Finlay Limestone as well as the beds of Cox Sandstone abruptly changes. Along the ridge on which JUDGE triangulation station is located, the strata dip 30° E-SE.

This change in attitude is interpreted to be the result of increased movement to the southeast along the normal fault that traverses the length of Speck Ridge. Immediately south of the fault that transects the ridge, the crest of the overturned anticline has been moved down against the still steeply dipping limb of the syncline to the northeast.

In the area that lies between Horse Canyon (J.0–10.1) and the Speck ranchhouse, the compression created not only the imbricate thrust faults in the thrust sheet but also numerous small folds. Most of the fold axes were perpendicular to the greatest principal stress.

At the northeast end of the thrust block of Bluff Limestone that is immediately south of Pagoda Hill (H.6–8.5), the gently dipping beds of limestone bend sharply upward; dip there is 55° W. At the southwest end of this small thrust block, the attitude of the gently dipping beds abruptly steepens to about 65° SW. The dip of the beds roughly parallels the dip of the thrust fault, and the net effect is a monoclinal fold in the overthrust block of limestone of the Bluff Formation. There are two small southeast-plunging folds, asymmetrical to the southwest, in the nearby Bluff Formation: an anticline in the overthrust sheet and a syncline in the overridden block.

Although the Yucca that is exposed east of the Speck ranchhouse is little folded, the Yucca in the Red Hills has been compressed into numerous small folds, many of which are asymmetrical. The folds in strata of the Yucca and the Bluff in small outcrops southeast of Red Hills also reflect the response of the rocks to the compressive stress régime of the Laramide orogeny. Asymmetry of the folds in Red Hills as well as that in the small outcrops to the southeast is both northeast and southwest.

Northwest, along the dip slope of Devil Ridge opposite Back Ridge, the Finlay is gently folded. Along the northeast flank of Back Ridge, smaller but closer and overturned folds accompanied the creation of the relatively larger overturned Back Ridge anticline. The northeast, overturned limb of this anticline dips 55° to 65° SE.; the southwest limb dips 30° to 50° SW. In the Finlay just north of the water gap, a small doubly plunging syncline is overturned to the southwest.

At least one large fold and possibly several smaller folds lie between Back Ridge and Devil Ridge. As shown in section A-A′, a syncline overturned to the northeast separates the two ridges.

The change in strike of strata in the vicinity of Grayton Lake suggests that the foreland block might be located on the southwest flank of a northwest-plunging anticline. No evidence of the northeast flank of such a fold has been found to the north, however; structurally this area is probably a homocline. The change in strike west of Grayton may be the result of gentle, southwest-plunging folds.

Throughout the Devil Ridge area the dominant trend of normal faults is northeast; the secondary trend is northwest. Only along a few of the normal faults has movement been greater than a few tens of feet. The faults are largely near vertical or vertical; many of the minor faults, especially those in the low-lying ridges of the foreland block, are difficult to see on the ground.

At Yucca Mesa, several faults with throws of 100 to 300 feet have displaced the Yucca and Bluff Formations. Faults with slightly smaller throws have displaced the same formations at Love Hogback.

At least two reverse faults are believed to have been the locus of much later movement during the period of normal faulting. The first is the fault that extends the length of Speck Ridge. Initial movement along the fault thrust the southwest block to the northeast, which resulted in beds of the underlying block being dragged upward and beds of the overlying block being overturned. This zone of weakness persisted through time, and during a later stress régime a normal fault developed along which the southwest block moved down relative to the northeast block (sec. B-B′).

The roughly east-west fault that truncates the large anticline (J.0–8.9) in which Finlay is folded asymmetrically to the southwest, may be a normal fault or it may be a strike-slip fault related to the Eagle Spring fault. If it is a normal fault, minimum movement along it must have been about 1,700 feet to account for the missing Cox Sandstone. If it is a strike-slip fault, strike separation would probably be about 5,000 feet.

Volcanic rocks in Black Butte and in the mountains to the east-northeast appear to have been displaced vertically by a fault, which has offset the southeastern half of Speck Ridge during an earlier period of strike-slip movement. The outpouring of the lava occurred long after the strike-slip movement.

Probably most of the mountain blocks in Trans-Pecos Texas are bounded by normal faults. The resulting basins or grabens have been filled with debris eroded from the mountains or horsts. Although no direct evidence of such boundary faults exists in the Devil Ridge area, water wells along the Southern Pacific tracks 900 to 1,000 feet deep and still in basin fill indicate that a depression at least a thousand feet deep exists roughly parallel to the mountain front. This depression is probably the result of block faulting and not erosion or folding. There is a similar basin on the southwest flank of the Devil Ridge area. The Devil Ridge area could be bounded on the southwest by normal faults with stratigraphic separations approaching 1,000 feet. There and throughout the map area, boundary faults are roughly parallel to the fold axes.

Relatively recent movement along faults just east of Red Light has cut the alluvial fill, but erosion has kept pace with the faulting. A fault scarp a foot or two high exists in a few places; elsewhere there is no difference in elevation across the fault. An anomalous north-northwest-trending cut in the alluvium (G. 2–8.9) southeast of Triple tanks and southwest of Little Hill may be the surface reflection of an ancient fault hidden beneath the alluvium, or it may be a recent fault along which erosion has created a cut about 2,000 feet long, 15 to 20 feet wide, and up to 5 feet deep.

STRUCTURAL FEATURES OF EAGLE MOUNTAINS

Steeply dipping, southeast-striking beds of Espy Limestone (J.7–9.2) disappear beneath the rhyolite northeast of Black Butte. There is little doubt that the complex and diverse structure of the Cretaceous rocks of the Devil Ridge area extends east and southeast beneath the blanket of volcanic rock of the Eagle Mountains. The general lack of stratification within the volcanic rocks masks the effects of post-volcanism normal faults.

Devil Ridge(?) fault.—What is probably a southeast extension of the Devil Ridge thrust fault is exposed south-southwest of Eagle Spring on the flanks of TC Peak and in Coal Mine Arroyo. Although the fault trace is covered by alluvium, steeply dipping *Orbitolina*-bearing limestone beds of the Bluff Formation overlie steeply dipping beds of sandstone and shale of the Chispa Summit Formation. Generally, the fault strikes northwest and dips gently southwest; locally, according to Smith (1941, p. 77), it dips gently northeast. Despite the steep and erratic dips in rocks above and below the fault, the sinuous trace in the vicinity of TC Peak indicates that the fault plane has a gentle dip. Stratigraphic separation is less than that in the Devil Ridge area where the Yucca overlies the Chispa Summit along the Devil Ridge fault. West of Eagle Spring, between Horse Canyon and Goat Canyon, isolated blocks of limestone of the Bluff Formation are probably part of the overthrust block.

There are two small klippen of limestone of the Bluff Formation on the east flank of TC Peak. Southeast of TC Peak the only evidence of the Devil Ridge fault is a block of limestone, questionably identified as Bluff, about 2,000 feet south-southeast of Carpenter Spring; this limestone may be part of the Devil Ridge thrust block or it could be a xenolith within the volcanic rock of the lower rhyolite.

Five miles southwest, in the valley south of Wyche Ridge and east of Eagle Bluff, the Chispa Summit Formation is sparsely exposed. Probably the Chispa Summit is in thrust-fault contact with the Yucca Formation along the southern margin of the valley, although this contact may be everywhere covered. That the fault may be an extension of the Devil Ridge thrust fault is a reasonable hypothesis. The fault is in proper alignment, and the stratigraphic separation is about the same.

Because the age of the lowermost volcanic rocks of the Eagle Mountains that overlie the Devil Ridge thrust is probably middle Tertiary, the thrust faulting appears to belong to the late Cretaceous—early Tertiary Laramide orogeny.

Carpenter fault.—The high-angle, northwest-trending Carpenter thrust fault parallels the northeast flank of the Eagle Mountains and repeats the upper part of the Cretaceous section. Stratigraphic separation varies along the strike of the fault from about 600 to 900 feet. Along the Carpenter fault north of the Rhyolite fault, the Espy is in juxtaposition with either the Chispa Summit or the Buda, and where the Carpenter fault is exposed south of the Rhyolite fault, the Espy is opposite the Buda Limestone. The fault can be traced for more than 7 miles; it is offset by northeast- or east-trending faults. At an exposure on the northeast flank of the ridge northeast of Carpenter Spring, the dip of the fault is 63° SE.; the fault trace is also exposed a short distance to the north in Carpenter Canyon. No evidence has been found that the Carpenter fault cut the volcanic rock. It is suggested that the faulting preceded the volcanism; in other words, this is a Laramide fault. Except for minor reversals, the Carpenter fault probably dips southwest; if so, it is a high-angle thrust fault or a reverse fault.

Spar Valley fault.—The Spar Valley fault is exposed at the upper end of Spar Valley and probably extends almost the length of the valley. The fault plane was penetrated by four diamond-drill holes, and it is exposed in a drift in shaft 1 (Gillerman, 1953, p. 43). The fault dips generally 20° to 30° SW. and cuts out some of the beds. There is a question, however, whether the fault was originally a low-angle normal fault that was later tilted or whether it was originally a low-angle thrust fault that originated after tilting of the strata and their intrusion by rhyolite. Although Gillerman (1953, pp. 43–44) favored the latter hypothesis, it is not certain that the Spar Valley faulting is later than the intrusion of magma or the extrusion of lava. Perhaps both the Spar Valley fault and the Carpenter fault are results of Laramide compression.

Minor thrust faults. — A low-angle, southwest-dipping thrust fault has displaced the Hueco Limestone to the northeast along the base of Espy Ridge. At MS 14 (L.2–14.7), a low-angle thrust fault has displaced the Hueco Limestone an unknown but probably short distance. In the Carpenter Spring area, southwest of Espy Ridge, the Espy Limestone has been displaced by two minor, parallel, northwest-trending thrust faults. In the large hill (M.7–15.3) just north of Wyche Ridge, the Cox Sandstone has been folded and thrust east-northeast over Finlay Limestone.

Earlier workers interpreted the nearly east-west faults that transect the Eagle Mountains as younger than the eruptive rocks because two of these faults displaced the extrusive rocks and one of them displaced part of the syenite stock. These and similar faults are probably left-lateral strike-slip faults that originated during the Laramide orogeny with the greatest principal stresses aligned east-northeast and west-southwest. Later "normal" movement along these faults in response to an entirely different stress régime offset early Tertiary eruptive rocks.

Rhyolite fault.—Near the east end of the Rhyolite fault the dip is 77° SE. In the vicinity of shafts 2 and 3, which were sunk along this mineralized fault, the dip is 60° SE. (Gillerman, 1953, p. 47). The strike separation of the Eagle Peak Syenite along the fault is about 1,000 feet; the strike separation of the Cretaceous formations is 1,500 to 2,000 feet. On the north flank of Mine Peak where the fault cuts the Bluff Formation (K.8–14.2), well-displayed slickensides have a hade of 75°. The inference is that the latest movement of rock along the Rhyolite fault was "normal" and was later than the volcanism; earlier, left-lateral strike-slip movement offset the pre-Cenozoic rocks. Although well exposed where it cuts sedimentary and metamorphic rocks, the Rhyolite fault is difficult to trace in the volcanic rocks to the west. The alignment of Frenchman Canyon suggests that it may well be the locus of the west end of the fault.

Wind Canyon fault.—The Wind Canyon fault is roughly parallel to the Rhyolite fault. Near the junction of Wind Canyon and Spar Valley, Cretaceous rocks along the fault have a strike separation of about 2,000 feet. To the west the fault has offset the volcanic rock as well as the Eagle Peak Syenite; strike separation along this part of the fault is about 400 feet.

Again, the discrepancy between the strike separation of rocks of Cretaceous and Tertiary age indicates that there could have been at least two periods of movement along the fault: (1) a pre-eruptive left-lateral strike-slip movement; (2) a post-eruptive "normal" movement, south side down. The east-west fault at the Silver Eagle mine on the west flank of the Eagles may be a continuation or a branch of the Wind Canyon fault. In the upper reaches of Wind Canyon, the dip of the Wind Canyon fault is 75° N-NW. (Gillerman, 1953, p. 66, fig. 8); farther east, at the outcrop of Cretaceous rock, the fault is probably vertical or near vertical.

Eagle Spring fault.—West of Eagle Spring the Chispa Summit Formation is separated from the Bluff, Cox, and Finlay Formations by a rhyolite dike which intruded along the Eagle Spring fault. The strike separation along this part of the fault is 1 to 1½ miles. East of Eagle Spring, the Hueco and Bluff Formations have been brought into juxtaposition along the fault; the rhyolite that was intruded along the fault disappears about 3,000 feet east of Eagle Spring.

It is possible that the Lone Hill fault is also a left-lateral strike-slip fault that disappears westward beneath the terrace gravels and beneath the Devil Ridge thrust. The northwest part that leads to the junction of the Eagle Spring fault could be a later normal fault, with the east side downthrown. Blocks along the Lone Hill fault, however, probably experienced only one general period of movement: a late Tertiary faulting that raised the Lone Hill block relative to the area south and west. The Lone Hill fault is a normal fault throughout its length. North of Eagle Spring there are several nearly east-west faults that may be left-lateral strike-slip faults.

There is a small, overturned, isoclinal fold (K.2–14.5) in Precambrian rock several hundred feet north of the end of the road that leads to the old mine in the Precambrian rocks. There are also crenulations and chevron folds in the phyllite members of the mixed units (Flawn, 1953, p. 49).

The large hill of Permian rock northeast of Eagle Spring is a faulted and breached, doubly plunging anticline. There are small north-northwest-plunging folds in the Buda Limestone about 500 feet north of the point at which Carpenter Creek cuts through the westernmost outcrop of Buda, and a poorly exposed northeast-trending syncline lies west of the northwest end of Espy Ridge. This fold is indicated by opposing dips in isolated blocks in which the Buda, Espy, and Eagle Mountain Formations are exposed. In the Cox (M-15) just east of the windmills at the old Yarbro place, an asymmetrical, south-southeast-plunging anticline was created along the leading edge of a northeast-moving thrust block. The southwest flank has a dip of 19°; the steep northeast flanks dip 58°.

There seems to be a broad east-south-east-trending fold in the lower part of the volcanic rock that crops out in Cottonwood Canyon. At the mouth of the canyon, the south limb of the fold dips under the terrace gravel at an angle of about 25°. Much of this "folding" may have been the result of adjustment of overburden during the outpouring of lava.

The dip of Cretaceous rocks peripheral to the Eagle Mountains and of the overlying volcanic rock is generally centroclinal. In describing the structure, which trends northwest, Gillerman (1953, p. 40) proposed the name Eagle Mountain syncline; it is shown in structure sections C-C′ and D-D′. Because the Cretaceous rocks were tilted during the Laramide orogeny, there is a disparity in most places between their dip and that of the overlying volcanic rock.

The primary trend of the normal faults of the Eagle Mountains is north-northeast; throws are generally less than 200 feet. An exception to this generalization is the northwest-trending Mine fault. As determined by subsurface data from mine shafts and diamond-drill holes in the area just south of the Rhyolite fault, the Mine fault splits into two faults: one branch dips 30° to 50° SW., and the other dips 60° to 77° SW. (Gillerman, 1953, p. 44). The two were mapped as a single fault. This fault extends southeast along Spar Valley, where it is largely covered by alluvium and terrace gravel. There the lower part of the Finlay is opposite the lower part of the Espy; rhyolite has intruded in places along the fault.

Northwest of the Rhyolite fault, along which late movement offset the Mine fault about 200 feet, the Mine fault runs north-northwest to the Lone Hill fault. Stratigraphic throw increases northward where Cox and Espy are in juxtaposition along the fault. Rhyolite has intruded along the fault and elsewhere in the area just north of the Rhyolite fault.

The nearly east-west strike-slip faults described earlier had a later, post-volcanism "normal" movement. This is indicated by the offset of the volcanic rocks along the Rhyolite and Wind Canyon faults. There may have been movement along the other east-west faults at this time.

Just south of Eagle Bluff, at the junction of the Eagle Mountains and the Indio Mountains, a fault truncates the northwest-trending rocks of Bramblett Ridge as well as the folded rocks of the Yucca and Bluff Formations to the northeast. The sense of relative motion along this fault is not known.

The Eagle Mountains are probably bounded on the northeast and the southwest by normal faults whose displacement can only be estimated by the depth of the bolson fill as determined by deep water wells. Late movement along or at least parallel to these boundary faults is indicated by the northwest-trending faults (N.0–9.8) in the terrace gravel southwest of the mouth of Snowline Canyon.

STRUCTURAL FEATURES OF INDIO MOUNTAINS

Structure of the Indio Mountains is dominated by north-northwest-trending Laramide faults and a major northwest-trending Tertiary normal fault, the Indio fault, that extends almost the length of the mountains and dropped the west block down. East of the Indio fault, the entire Cretaceous section is exposed in relatively persistent strike valleys and ridges; it is repeated in places by thrust faults but only slightly broken by normal faults. West of the Indio fault, the Yucca Formation predominates and displays a "broken-glass" fault pattern and extremely irregular topography. The normal faulting along the Indio fault displaced the volcanic rocks in the Flat Top area with respect to correlative rocks along Green River to the east. Although several high ridges now separate these outcrops, the Tertiary lavas were presumably co-extensive. The dip of the Indio fault is about 75° SW. (Bostwick, 1953, p. 46).

Several lines of evidence indicate that the block west of the Indio fault is an overthrust sheet:

(1) The west block is much more intensively faulted than the block to the east, and the topography and the fault pattern are much more irregular.

(2) There is a marked difference in degree of erosion between the two blocks. Along most of the Indio fault, erosion has removed all but a part of the Bluff and Cox Formations from the west block. Just east of the fault, formations as young as Buda are still present. The difference in amount of erosion is difficult to explain unless the east block was less broken and was protected from erosion by a thrust sheet that has since been removed.

(3) Less conclusive but also suggestive is the lack of volcanic rocks on the east block. If the two blocks were once continuous and covered with volcanic rock, remnants of this rock might be expected on both sides of the Indio fault instead of only on the west side.

The evidence suggests that the west block is part of an overthrust sheet that moved generally from west to east. The east part of the sheet is preserved between the Squaw fault and the Willoughby fault. The west part of the overthrust sheet lies west of the Indio fault. Between the Indio fault and the Squaw fault, the overthrust sheet has been eroded from the central block.

Willoughby fault.—Because of the widespread cover of volcanic rock, alluvium, and terrace gravel, positive correlation of the Devil Ridge fault at Devil Ridge with thrust faults to the southeast is not feasible.

It seems probable that in the valley east of Eagle Bluff, the trace of the Devil Ridge thrust leads east-southeast from beneath the volcanic rock to a point near the mouth of the valley where the trace turns south. It first becomes visible in the Indio Mountains at the east end of Oxford Ridge where the trace is the contact between the overlying Yucca and underlying Chispa Summit Formations. This, then, suggests that the Willoughby fault is the south-southeast extension of the Devil Ridge fault. The Chispa Summit dips beneath the Yucca.

Throughout the length of Willoughby Ridge, the trace of the Willoughby fault is the contact between the Yucca and Espy Formations. About a mile south-southeast of Willoughby Ridge and just north of the Indio Pass road, the trace is visible where a small mass (S.4–17.2) of overturned Espy Limestone protrudes through the thrust sheet. Still farther south-southeast, gray, rough-weathering limestone seems to overlie the Chispa Summit. This outcrop of limestone was tentatively identified as Finlay but only on the basis of gross lithology. No diagnostic fossils were found there. From this point south, the trace of the Willoughby fault is hidden.

Squaw fault.—Dip of the Squaw fault ranges from northeast to east-southeast. Comparison of its trace with the trace of the Willoughby fault (secs. E-E′, F-F′, G-G′, H-H′) suggests that they are but parts of a single fault. Northward the trace disappears beneath terrace gravel; to the south it terminates (V.4–16.7) against the Indio fault. The fairly straight course of the north half of the trace indicates that that part of the fault plane dips relatively steeply. It flattens to the south, however, as shown by the sinuous trace.

Near where the road just south of the mouth of Snake Canyon passes through a barbed-wire fence high on a gravel hill (V.3–16.3), there is a good view of the Yucca thrust upon the Espy. There, conglomeratic redbeds overlie beds of gray limestone; the fault plane dips 10° to 15° S-SE. Northward, where the strike gradually swings northwest then back to north, the dip is northeast of east. The thrust sheet is composed of Yucca, but rocks as young as Finlay (S,T-17.3) make up part of it. Near the north end of Willoughby Ridge, a small fenster (Q.5–15.3) exposed Chispa Summit beneath the thrust sheet.

The most prominent topographic features of the northern Indio Mountains are part of the thrust sheet. Squaw Peak, about 5,400 feet above sea level, is composed of steeply dipping beds of red-brown Yucca conglomerate. Viewed from the northeast or southwest, Squaw Peak appears to be a mesa; from the northwest or southeast, its true "knife edge" profile is evident.

Southward along the trace, the Squaw fault, a diagonal fault, truncates increasingly younger Cretaceous rock. The color and lithologic contrast of the Yucca and the younger beds make that part of the trace clearly evident. To the north, where the trace lies entirely within the Yucca, its position is indicated primarily by a line of truncation of beds in the overridden block. Folding of the fault plane (sec. F-F′) may have been partly contemporaneous with or later than the thrust faulting.

Bennett fault.—The trace of the Bennett fault roughly parallels the trace of the Squaw fault. To the north, the Bennett fault terminates against the Indio fault, and displacement decreases to the southeast where the fault dies out into an anticline (U.0–16.8), half a mile west of East Ridge. This fault is a diagonal fault, for it truncates strata of the Yucca, Bluff, Cox, Finlay, Benevides, and Espy Formations. The dip of the fault plane probably averages 30° to 40° at the surface. The ostensible horizontal displacement of the Bluff strata by the fault is about 6,000 feet, which was caused by the northeast block overriding the southwest block. Movement could have been entirely of the dip-slip type (Bostwick, 1953, pp. 27–32).

Borrega fault.—The Borrega fault is not readily evident in the field because its trace is almost within the Yucca Formation. The fault appears to extend the length of the mountains, but in several places its trace is obscure. It is not certain, for example, that the thrust fault that leads south-southwest from a point near the termination of Red Mountain fault is part of the Borrega fault. The average trend of the trace is N. 20° W. The dip of the fault is variable, but a generally steep dip, i.e., 30° to 40° SW., is indicated by the relatively straight trace. The Borrega fault is one of several west of the Indio fault that have overthrust the Yucca unknown but probably short distances to the northeast.

Red Mountain fault.—Another relatively high-angle fault along which beds have been overthrust to the northeast is the Red Mountain fault. Its trace is roughly parallel to the trace of the Borrega fault, but the Red Mountain fault is only about 3 miles long. The overthrust sheet is composed largely of the red-brown sandstone, siltstone, and conglomerate of the Yucca, but near the north end of the fault, limestone of the Bluff and sandstone of the Cox Formations form part of it. They, in turn, appear to have been covered by beds of the Yucca which moved northeastward along a gently southwest-dipping thrust fault.

Minor thrust faults.—In the Indio Mountains, as in other parts of the map area, the incompetent rock of the Yucca responded readily to the compressive stresses imposed on the region during the Laramide orogeny. Thrust faults with minor movement are abundant in the Indio Mountains. The traces of these minor faults, most of which trend at very small angles to the strike of the beds, are recognized primarily by truncation of beds along the fault.

No strike-slip faults have been recognized in the Indio Mountains. Some of the so-called normal faults that have a general eastward trend may actually be strike-slip faults.

Folds are more numerous in the Indio Mountains than in other parts of the map area. Fold axes are generally aligned perpendicular to the inferred direction of the greatest principal stresses of the thrust faulting with which, indeed, many of the folds are closely associated. The eastern part of the overthrust sheet between the traces of the Squaw and Willoughby faults contains a multitude of small and large folds.

A southeast-plunging synclinorium lies immediately southwest of and roughly parallel to Willoughby Ridge (Q,R-15,-16). Superimposed on it are a number of smaller folds, some of which are overturned to the northeast. The synclinorium extends south-southeastward along the eastern margin of the mountains, but only the west limb is exposed. The anomalous dips in the easternmost exposures of the Yucca, Bluff, Cox, and Finlay Formations that compose the west limb doubtless reflect folds similar to those in the Yucca and Bluff Formations in the nose of the synclinorium to the north. South of Squaw well, the folds are less well expressed, perhaps because of faulting contemporaneous with the folding, or because of later faulting, or both.

Eroded folds in the east part of the overthrust sheet north of Oxford form some of the most distinctive topographic features of the Indio Mountains. Bramblett Ridge is the steeply dipping and in places overturned east limb of an anticline whose western limb has been dropped down by the Indio fault (sec. E-E′). Bramblett Ridge is also the west limb of a sharp, faulted syncline whose axis parallels the ridge. To the northeast, about 6,000 feet above sea level, is the summit of the east limb of the breached north-northwest-trending Horse Peak anticline. The limbs are made up of beds of resistant limestone of the Bluff Formation, which dip away from the axis at angles of 15° to 20°. Erosion has exposed Yucca in the core of the fold.

The axis of Oxford syncline is roughly parallel to Oxford Ridge. Interestingly, both of these features trend northeast, that is, their trend is almost perpendicular to that of the other folds of the Oxford area. A greatest principal stress oriented northwest-southeast was associated with this folding as well as with the minor thrust faults that also parallel Oxford Ridge.

Northeastward, along the margin of the Indio Mountains, strata of the Bluff and Yucca Formations have been deformed in a series of minor anticlines and synclines. These folds may reflect the proximity of this area to the leading edge of the overthrust sheet.

Willoughby Ridge is the west-dipping limb of an overturned syncline; presumably it is a drag fold along the Willoughby thrust fault that was developed as the overriding block moved northeast (sec. F-F′). The trace of the axial plane of this fold lies within the outcrop of the poorly exposed Chispa Summit Formation northeast of the ridge.

A gentle syncline that appears to plunge northwest is inferred to be in the block beneath the eastern part of the overthrust sheet; a gentle anticline may lie immediately to the east (sec. F-F′).

About 0.7 mile northeast of Palmas

well (abandoned) is the breached anticline into which the Bennett fault dies as it extends south. The north-northwest-trending fold is expressed in the Espy Limestone; the limbs dip about 20° to 25°. The fold axes are offset by an east-west transverse fault that lies just north of the road. South of the fault the axes are offset to the west several hundred feet. Other small folds of similar trend are expressed in the Espy in this general area.

A window in the easternmost overthrust sheet, about 0.7 mile west of Escondido well, exposes the Espy, Eagle Mountains, and Buda Formations in a south-plunging anticline upon which are superimposed small tight folds. Along the west limb the Espy has been thrust over the Buda, and in places along the east limb the Buda is overturned. The distinctive brown-weathering Eagle Mountains Sandstone is exposed in the center of the fold; along the east limb, the Bluff of the overthrust sheet is in contact with the Buda of the underlying block. The large anticline and the smaller, superimposed folds as well as other small folds nearby reflect the general east-west alignment of the greatest principal compressive stresses during the Laramide orogeny.

The western part of the overthrust sheet, which includes that part of the mountains west of the Indio fault, is characterized by a maze of faults and folds, although the north-northwest trend of the structural elements is still dominant. Just north of Oxford Draw and west of the Borrega fault, beds of the Yucca are tightly folded and displaced by minor thrust faults. Folds plunge north-northwest as well as south-southwest. About a mile and a half south of Oxford Draw and just west of the Borrega fault, there is a broad north-plunging anticline in the Yucca Formation. Due east of this fold and immediately west of the Indio fault, the Yucca of the overthrust sheet is displaced by minor thrust faults, along which the overthrusting was to the west or west-northwest. This movement was accompanied by folding which produced 15° to 20° centroclinal dips in the Yucca. The basin (S.7–14.3) has a maximum diameter of about 1,200 feet.

The Bluff Formation in the outcrop west and northwest of the Indio ranchhouse is intensely folded. Grossly, the structure consists of a north-northwest-trending syncline with an axial fault. Toward the south, the syncline is overturned to the southwest. A west-northwest transverse fault abruptly terminates the trend.

A tight, north-northeast-plunging anticline in the Bluff Formation and a south-plunging anticline in the Cox Sandstone extend from beneath the overthrust sheet at the north end of Red Mountain. The tight anticline in the Cox is particularly well exposed high on the cliff on the south side of the draw that runs north of Red Mountain. A fault, perhaps a thrust fault, lies between the two folds; the trace of this fault is coincident with the Yucca-Bluff contact.

To the northwest, despite the many faults and small folds in the Yucca, a series of broad anticlinal folds are offset by more obscure transverse faults. The Yucca along the west flank of the Indio Mountains north of Red Mountain dips west or southwest. East of the point at which the Red Mountain fault terminates against a southeast-trending fault, the east limb of a south-plunging asymmetrical anticline (V.5–15.4) dips at angles approaching 80°.

The asymmetrical Lost Valley syncline just north of the Rio Grande is the largest fold of the western part of the overthrust sheet. Strata of the west limb commonly dip 50° to 60°; those of the east limb, 25° to 30°. Normal faults have displaced beds along the axis of the syncline (sec. H-H′). East of the syncline, there is probably an equally large south-plunging anticline (sec. H-H′).

Lost Valley syncline is the northward extension into Texas of a large, doubly plunging synclinal horst; the northern part of it overlooks the Lost Valley area and is referred to by local inhabitants as Sierra Bosque Bonito. The strata of the west limb of the syncline continue across the Rio Grande with very slight horizontal separation. Near the river, the strata of the east limb of the syncline are largely covered. It is suggested that the axis of the syncline of Sierra Bosque Bonito is actually farther east than shown on previous maps and that there is little or no offset of the axis north and south of the river, although there the axis may bend sharply. Along the west margin of the mountains just north of the Rio Grande, small but tight folds in the Yucca are related to faults along which overthrusting was northwest.

A gentle down-warping along the southeast margin of the mountains is indicated by an east dip of about 15° in the volcanic rocks of Teritary age. The gravel (QTg) just north of Campo Bonito (W.2–16.7) dips 5° to 6° SE.

Bostwick (1953, pp. 42–44) considered the northeast- and east-dipping strata of the block between the trace of the Indio fault and the trace of the Squaw fault to be the east limb of a large, northwest-trending anticline which he called the Indio Mountains flexure. The western part of the overthrust sheet probably conceals the axis as well as the west limb of the Indio Mountains flexure; in other words, the west limb is in the underthrust block beneath the west half of the Indio Mountains.

Indio fault.—The Indio fault runs northwest through the Indio Mountains; along most of its 13.5-mile trace it is marked by a southwest-facing, resequent, fault-line scarp. To the northwest, the trace is approximately parallel to the strike of the beds; south of the Indio ranchhouse, however, the fault cuts across the beds at an ever-greater angle. At the mouth of Snake Canyon, the trace of the fault is at an angle of 60° to the strike of the beds. The relatively straight trace indicates that the fault has a steep dip. In the vicinity of the centroclinal fold in the Yucca (S.7–14.3), the dip of the fault plane is about 75° SW. (Bostwick, 1953, p. 46). Structure sections indicate as much as 7,000 feet of separation in places (sec. F-F′).

The Indio fault displaces the volcanic rock of the Indio Mountains. Rocks of the Garren Group along the east margin of the mountains are separated by several high ridges from those in the Flat Top area in the center of the mountains. Presumably the volcanic rocks in the Flat Top area were lowered to their present position by movement along the Indio fault. It is likely that Cottonwood Canyon owes its origin to the Indio fault.

Bramblett Ridge area.—Displacement along the normal fault immediately northeast of Bramblett Ridge is about 1,100 feet. This dropped the southwest-dipping beds of sandstone of the Cox on the east against near-vertical limestone strata of the Bluff Formation on the west.

Lost Valley syncline.—Steeply dipping normal faults roughly parallel to and near the axis of the Lost Valley syncline bound a small horst about 800 feet wide. Displacement along the west fault is about 1,200 feet; along the east fault, about 700 feet (sec. H-H′).

Marginal faults.—The west margin of the mountains is bounded by a normal fault. A relatively high scarp marks the straight line of contact between the highstanding Cretaceous rocks of the Indio Mountains and the topographically lower bolson fill and terrace gravel. In some places, beds of the fill immediately adjacent to the margin of the mountains dip as much as 25° toward the mountains; the dip indicates movement along the boundary fault since the fill was deposited. Along the east margin of the mountains there is no fault scarp similar to that along the west side. The Cretaceous rocks and the Tertiary volcanic rocks seem to dip gradually beneath the terrace gravel and bolson fill along Green River. At one place the outcrop of Tertiary volcanic rock extends eastward across Green River into the Van Horn Mountains. Probably the Green River bolson (Twiss, 1959b, pp. 127–128) is a half-graben, bounded on the east by a normal fault and on the west by a monocline. The southern part of the Eagle bolson (Twiss, 1959b, p. 126) may also be a half-graben, for there is no evidence of a boundary fault along the northeast margin of the Indio Mountains. The half-graben to the south may change to a graben northward where southeast-trending Cretaceous strata of the Eagle Mountains appear to have been sharply truncated.

Movement later than the deposition of the bolson fill is indicated by the varied dips in the clearly stratified fill that is well exposed east-northeast of the Bramblett ranchhouse. Normal faulting of Quaternary age is attested by offset of the Qg2 terrace gravel west of the Indio Mountains. Near-vertical faults in the bolson fill (W.5–17.0) southwest of Campo Bonito offset the strata several feet.

Washboard Hills (T.3–11.3), a series of arcuate corrugations, symmetrical in cross-section, trend a few degrees south of east. Probably the area was once a "normal" Qg3 terrace gravel resting on bolson fill; the corrugations are offsets along a series of arcuate, parallel normal faults. Several north-northeast-trending faults have also cut the rock in the Washboard Hills. It is possible that this anomalous feature is the result of creep of the fill and overlying gravel south-southwest along the "floor" of the graben. To the northeast, a high relatively abrupt scarp in the bolson fill and the Qg1 terrace gravel may be a breakaway scarp.

GEOLOGIC HISTORY

PRECAMBRIAN TIME

The earliest geologic event recorded in rocks exposed in the map area as well as in Trans-Pecos Texas is the deposition of the sediments of the Carrizo Mountain Formation in a geosyncline within the largely granitic and granodioritic Texas Craton (Flawn, in press). Flawn believed that the over-all homogeneity of the metasedimentary rock of the Carrizo Mountain Formation indicates that it is a single sedimentary series. Because the outcrop area of the Carrizo Mountain Formation is relatively small and because subsurface control on the basement in the region is scanty, the shape, orientation, and areal extent of this geosyncline are unknown.

The geosynclinal deposits were subjected to folding and regional progressive metamorphism of low to medium grade; intrusion by rhyolite, then diorite followed (Flawn, in press). The grade of the metamorphism increases from northwest to southeast. In the Carrizo Mountains and Eagle Mountains, low-grade metamorphism is indicated by the green-schist facies in which many sedimentary structures are preserved, whereas in the Van Horn Mountains to the southeast, medium-grade metamorphism is indicated by the amphibolite facies in which most sedimentary structures have been obliterated.

The sills of diorite that intruded the Carrizo Mountain Formation of the Eagle Mountains and elsewhere were converted to amphibolite by a second period of deformation. During this second orogeny, the geosynclinal deposits of the Carrizo Mountain Formation were cataclastically and retrogressively metamorphosed and overthrust northward.

A younger red, unfossiliferous, arkosic, cross-bedded, coarse-grained local continental deposit—the Van Horn Sandstone—has been designated Precambrian (?) by King (1953, p. 90).

PRE-PERMIAN PALEOZOIC TIME

During the Cambrian Period, most of Texas, including the Van Horn uplift, was undergoing erosion. Rock of latest Cambrian age is known in the Llano uplift as well as in the El Paso area.

The thin-bedded, quartzose Bliss(?) Sandstone of Early Ordovician age, 115 to 120 feet thick and well exposed on Beach Mountain just north of Van Horn, records the transgression of an epicontinental sea. The Van Horn region was not a site of continuous deposition throughout the Ordovician, however, for the El Paso Limestone, a 1,115-foot sequence of thick-bedded dolomitic limestone and dolomitic sandstone, lies disconformably on the Bliss(?) at Beach Mountain. The El Paso, in turn, is overlain by the dolomitic and cherty Montoya Limestone of Late Ordovician age, Silurian, Devonian, Mississippian, and Pennsylvanian rocks crop out in the Trans-Pecos region, and an even more nearly complete section is present in the subsurface. The map area and surrounding region were no doubt receiving sedimentation during much of the pre-Permian part of the Paleozoic Era.

A series of Pennsylvanian orogenies, the last of which in Trans-Pecos Texas extended into earliest Permian time, deformed the sediments of the Marathon geosyncline and uplifted and gently folded the Van Horn region to the northwest. Subsequent erosion removed much of the earlier Paleozoic rock; at least, on the northeast side of the map area, erosion was sufficient to expose and probably partly remove rock of Precambrian age.

The major structural elements that were created late in the Pennsylvanian Period and early in the Permian Period controlled sedimentation in the region throughout the Permian Period. The Eagle Mountains are on the southwest flank of the Van Horn uplift, a grossly domical high on the larger Diablo Platform.

PERMIAN TIME

The Early Permian sea that covered western Trans-Pecos Texas transgressed over an uneven erosional surface; the Powwow Conglomerate, a basal siliciclastic unit, filled topographic lows on this irregular pre-Permian surface. Recorded within the Powwow is the transition from a continental fluvial environment to an epineritic environment of deposition. The very finely crystalline fossiliferous limestone or micrite of the Hueco records the gradual advance of the neritic Wolfcamp sea onto the Diablo Platform.

Several thousand feet of rock of Leonard and Guadalupe age probably were deposited on the Hueco Limestone in the map area concomitant with the development of the classic Permian reefs to the north, east, and southeast, and with the development of the accompanying basin, reef, and marginal shelf facies. During the Ochoa Epoch, the map area, together with marginal shelf areas, rose above water as the Permian sea regressed toward Mexico.

EARLY MESOZOIC TIME

Erosion that followed the disappearance of the Permian sea from Trans-Pecos Texas eventually reduced the land to a low, irregular surface which R. T. Hill called the "Wichita paleoplain." The transgression of the Mexican sea over this vast, low-lying erosional surface began in Aptian time and continued uninterruptedly into the Early Cretaceous Epoch (Albritton, 1938, p. 1754; Huffington, 1943, p. 997).

CRETACEOUS PERIOD

The Diablo Platform and the differentially subsiding Chihuahua trough to the southwest, which was inundated by the Mexican sea, were the tectonic elements that controlled sedimentation in the map area during the Cretaceous Period.

COMANCHE EPOCH

The Yucca Formation, a siliciclastic and calciclastic near-shore deposit probably both marine and continental, includes the oldest Cretaceous rock exposed in the map area. During the advance of the Mexican sea, the regolith of the pre-Cretaceous surface was incorporated in the heterogeneous material that composes the Yucca. Transgression of the sea was so rapid that the sediments were poorly sorted.

Continued transgression created in the map area for the first time since the Permian Period, a neritic environment in which the limestone of the Bluff Formation was deposited. Conditions were somewhat unstable, however, as indicated by the sandy, oolitic, reef character of the lower part of the Bluff compared to the homogeneous, very finely crystalline *Orbitolina*-bearing limestone of the upper part of the formation. During a slow regression of the sea, marked perhaps by minor regressive and transgressive movements, the map area was for a long time the locus of a shore or near-shore environment in which reworked material was brought in and further reworked and cleaned. These environmental conditions accompanied by little or no tectonism were widespread throughout Trans-Pecos Texas, and the Cox Sandstone that resulted is characteristically a supermature orthoquartzite. The Cox Sandstone is the youngest Cretaceous formation that rests on Paleozoic and older rocks; thus, it marks the culmination of the transgression of the Mexican sea over the Diablo Platform.

The Finlay Limestone represents, thus far, the most extensive transgression of the Mexican sea into Trans-Pecos Texas. This transgression brought into the map area a marginal neritic sea in which rudistid and caprinid reefs or banks developed.

The increasingly brief interruptions of carbonate deposition, represented by the thin Benevides and Eagle Mountains Formations, as well as the homogeneity of the very finely crystalline (micrite) limestone of the Espy and Buda Formations, reflect increasing tectonic stability during the Comanche Epoch.

Once the Diablo Platform was inundated, the Mexican sea invading Trans-Pecos Texas merged with the Cretaceous sea advancing onto the continental shelf to the east. Westward, however, there is no certainty that the Mexican sea and the Pacific Cretaceous sea ever merged.

GULF EPOCH

The lithologically varied rock that constitutes the Chispa Summit Formation was deposited in a changeable neritic sea as well as along the shore in stagnant lagoons. There may or may not have been a brief period of subaerial erosion between the Comanche and the Gulf Epochs.

In the map area, erosion has removed that part of the Gulf Series younger than late Turonian, but sedimentation may have continued there until even into Tertiary time. As the sea retreated, well before the end of the Cretaceous Period, near-shore marine deposition gave way to fluvial and deltaic deposition, and this to continental deposition.

LARAMIDE OROGENY

The thrust faults and folds of the Eagle Mountains and vicinity record a part of the intense deformation that accompanied the Laramide orogeny. In the map area, the Chispa Summit Formation is the youngest formation now exposed that was certainly involved in the deformation. The time of culmination of the Laramide orogeny was later than the youngest Cretaceous rock and earlier than the oldest volcanic rock of the Rim Rock country. This places it as post-Campanian (probably Maestrichtian or later) and pre-Oligocene; that is, between latest Cretaceous and latest Eocene.

CENOZOIC ERA

Although the early part of the Cenozoic Era was a time of intense structural deformation, erosion was probably sufficient to maintain a relief of less than a thousand feet. By the time the first volcanic rocks were laid down in the map area, the maximum relief was about 500 feet. The irregular distribution of the volcanic rock units of the Eagle Mountains partly reflects the uneven surface over which the lava flowed.

The north-northwest to northwest trend of Laramide structural features that is so evident today probably controlled the topography of the erosional surface on which the volcanic rock was deposited.

VOLCANISM

Widespread volcanism in the region during the Oligocene Epoch, probably centered in the Davis Mountains area, spread a blanket of extrusive igneous rock over much of Trans-Pecos Texas. Few vents through which the volcanic rocks reached the surface have been identified, perhaps because these rocks still cover large areas. The volcanic outbursts that spread tuff, welded tuff, trachyte, and basalt over the Indio Mountains area were cyclic. Because the igneous rock section so closely resembles that of the Van Horn Mountains, and because the Pantera Trachyte thins westward, the source of the volcanic material was probably to the east. The thick section of volcanic breccia and flow breccia in the Eagle Mountains must have had a local source, although no vents have been positively identified.

INTRUSION

During the eruption of the material that now forms the lower rhyolite of the Eagle Mountains, the country rock was intruded by numerous sills and dikes of the rhyolite. Some time later, after the emplacement of the trachyte porphyry and the upper rhyolite and perhaps additional rock that has since been eroded, the rocks of the Eagle Mountains were intruded by the Eagle Peak Syenite.

The relative ages of the Eagle Peak Syenite, the diabase (Tdd), and the rhyolite (Trd) that generally intruded along east-west faults are uncertain, as is the relationship of the intrusion of those rocks to the time of normal faulting. Much of the normal faulting may have preceded the intrusion of the igneous rock. Certainly, it seems, for example, that the rhyolite and diabase intrusive bodies in the Eagle Spring area are intruded along pre-existing fractures. The same may well be true of all the dikes as well as of the stock of Eagle Peak Syenite. Whether these fractures, joints or faults, were formed during the episode or Tertiary block-faulting is not known. It is entirely possible that the diabase dikes and the late rhyolite dikes antedated the emplacement of the Eagle Peak Syenite.

FOLDING

In a few places in the region, folds in volcanic rocks indicate that there was late or post-volcanism compressive tectonism. Perhaps the strongest evidence for this late period of folding is the Colquitt syncline in the northern part of the Rim Rock country. In this fold, rock of Oligocene age is folded concordantly with the Cox and Finlay Formations of Cretaceous age (Twiss, 1959b, p. 149).

In the map area, perhaps the strongest evidence for post-volcanism compression is the change in attitude of the lower part of the upper rhyolite in Cottonwood Canyon. This, and several gentler warps in the volcanic rock of the map area, may, however, have resulted from subsidence that accompanied the extrusion of vast quantities of igneous rock.

BLOCK FAULTING

During the Laramide orogeny, western Trans-Pecos Texas and northern Chihuahua were near sea level, but about at the middle of the Oligocene Epoch, the region was uplifted several thousands of feet and block-faulted (DeFord and Bridges, 1959, pp. 292–293). Some of the intrusive rocks of the Eagle Mountains and vicinity may have been emplaced along normal faults that date from mid-Tertiary time, but their emplacement could have been earlier.

The differences in elevation created by the mid- to late-Tertiary block-faulting in the Eagle Mountains and vicinity led to the formation of an old gravel that is probably correlative with the Tarantula Gravel of the northern Rim Rock country. In the map area, the old gravel (Qtg) was recognized only in the Indio Mountains, where it probably resulted from erosion of the scarp created by the Indio fault.

Although the normal faults have several thousand feet of separation, movement along the faults was probably intermittent and slow enough to allow erosion to maintain differences in elevation of several hundred to a thousand feet. The faults that have displaced the bolson fill and later terrace gravel show that the normal faulting was long-lived; it may still be active.

From the time of the earliest block-faulting, the topographic depressions or grabens were filled by debris eroded from the adjacent highlands. Within the closed basins, such as Grayton and Eagle Flat and Salt Basin, this process continues today; within the open basins, material eroded from the highlands is sporadically moving to the Gulf of Mexico.

EVOLUTION OF DRAINAGE AND TERRACE DEVELOPMENT

Following the Laramide orogeny the region probably had a trellis drainage pattern with a prominent northwest trend parallel to the fold axes as well as to the hogbacks and ridges created by thrust faults. With the creation of the intermontane lowlands by block-faulting, drainage became closed, and as the fill buried the mountains the drainage developed a radial pattern. When the intermontane lowlands were breached and an open drainage system was again established, degradation began and has continued to the present day. As the streams cut downward through the fill, they were superposed on the older rocks. Much of the drainage, therefore, crosses structure at a high angle. Following the breaching of Red Light bolson and the establishment of an open drainage system, removal of the bolson fill and exhumation of the adjacent highlands began. This probably antedated the beginning of degradation in the Hueco bolson dated by Strain (1959, p. 377) as between late Kansan and medial Illinoian time.

The three principal terraces and several intermediate ones that are present from place to place are a record of changes in climate and/or base level which in turn changed conditions of erosion and deposition. The smooth, gravel-capped, upper surfaces of the terraces were developed when the controlling factors (climate, tectonic activity, lithology) were so adjusted as to allow the formation of a broad surface on which aggradation and degradation were approximately in balance. A change in one or more of the controlling factors caused the streams to seek a grade at a lower level, and the older surface is preserved as a gravel-capped terrace.

ECONOMIC GEOLOGY

WATER

This region receives less than 10 inches of rainfall annually, of which about 65 percent falls during the months of July to October inclusive in the form of short-lived but torrential thundershowers. Streams are ephemeral, but during infrequent but violent periods of activity they are effective agents of erosion. In the highlands they have developed dendritic patterns, whereas on the broad, gravel-capped pediments they have formed sub-parallel channels.

Surface water drains into four principal basins: Green Valley, Eagle Flat, Grayton Lake, and Red Light Valley. Eagle Flat drainage has been captured by Salt Flat through the water gap between the Carrizo Mountains and the Van Horn Mountains. Grayton Lake (C,-D-6,7) is a playa which receives water from a small part of the map area plus a much larger area, more than 100 square miles, north and east of Sierra Blanca. Green River and Red Light Draw are principal drainages in their respective valleys and are the largest tributaries to the Rio Grande in the map area.

The Rio Grande, principal drainage artery in the area, flows only intermittently, although scattered pools of water persist in its channel throughout most of the year. In time of heavy flood, flow in the salt-cedar-choked channel is so restricted that channel overflow and flooding of surrounding lowland are common. Water in the Rio Grande is withdrawn for irrigation on the Bramblett and Guerra farms, but, understandably, the Rio Grande is not a dependable source of water.

To retain as much surface water as possible, many U-shaped earthen stock tanks have been built across drainage channels in the low areas. In some narrow canyons in the mountains, rock-and-concrete dams have also been constructed to retain surface runoff. Low, earthen spreader dams, thrown across incipient gullies to retard erosion, are particularly numerous in the low, sparsely vegetated area just south of the Southern Pacific.

The economy of the region depends upon an adequate supply of ground water. There are no artesian wells, and springs are few and characterized by low flow rates. Ground water is lifted to the surface through wells equipped with windmills. The most productive aquifer is the gravel, sand, and silt of Tertiary and Quaternary age that fill the intermontane basins and floors of the canyons in the mountains. Ground water is also produced from sandstone and limestone of Cretaceous age and from volcanic rock of Tertiary age. Wells producing from the intermontane basin fill are characteristically stronger than wells producing from other aquifers. Some 65 wells produce ground water in the map area; the majority are equipped with windmills, but a few are pumped by butane-powered engines. The advent of rural electrification into the region has resulted in a number of wells being pumped electrically.

Springs in the area all have low flow rates or are dry. Eagle Spring (H.7–11.8) is the best known, because from about 1854 to 1882 it was the site of an overland stage stand. Other well-known springs are Squaw Spring (S.3–15.0), Oxford Springs (Q.3–13.9), Cottonwood Springs (M.8–12.7), Mesquite Spring (X.3–17.8), and Indian Springs (J.6–8.8).

Ground water throughout the area is potable with few exceptions. It is all satisfactory for stock and for irrigation.

Precipitation is the only source of recharge, and average rainfall recorded at the nearest weather station averaged only 8.2 inches over the 10-year period 1949–1958. Because the evaporative rate and percentage of runoff characteristic of the area are high, most of the precipitation is unavailable for recharge.

The movement of ground water is generally from the higher areas toward the intermontane basins. Water penetrating the topographically high volcanic rocks and intrusive igneous rocks of the Eagle Mountains percolates downward rapidly through the abundant fractures and joints. Restricted small reservoirs might exist, however, in the fractured volcanic rock. Movement of subsurface water in the sedimentary rock of the mountain masses is principally controlled by structure and to lesser extent by lithology.

Ground water movement in Green Valley is probably both northward and southward away from the threshold of volcanic rock that crops out just south of Double Wells ranchhouse and separates Eagle bolson from Green River bolson. In the Red Light Valley, barring some unknown subsurface obstruction, water in the subsurface probably moves southeastward toward the center and presumably the lowest part of the basin.

SOIL

A reconnaissance soil survey of Trans-Pecos Texas identified 10 soil types in the Eagle Mountains and vicinity, the most common of which were silty clay loam, gravelly loam, very gravelly loam, and rough stony land (Carter and others, 1934). In 1950, the district supervisors of the High Point Conservation District, which includes the map area, published a District Program and Work Plan that described soils and range condition. These reports point out that the soils of the area are largely immature and thus closely related to the bedrock from which they are derived. They are typical of an arid climate inasmuch as they are thin, calcareous, and characteristically underlain by caliche. Widespread bare rough and rough stony land are intermingled with immature residual soils containing abundant rock fragments. Despite relatively heavy rainfall in the mountains, mature soils occur there only in small, scattered patches. The slopes at the base of the mountains are characterized by more extensive but still relatively thin, calcareous soils. Still lower on the upper reaches of the valleys and flats are gravelly fine sands and loams. Alluvial soils, fine sandy loams, silty clay loams, and fine windblown sand occur farther down the valleys. The floors of the intermontane basins have deep, usually gypsiferous, and alkaline soils. The highlands of the Eagle Mountains and Indio Mountains are largely rough stony and broken land with non-calcareous soil material. Green River Valley and the southern half of Red Light Valley have shallow, medium-textured, gravelly soils. Grayton Lake area and the easternmost portion of Eagle Flat have deep, medium-textured, permeable soils. There are shallow, medium-textured, gravelly, permeable soils in the northern half of Red Light Valley and near the base of the mountains in Eagle Flat. Devil Ridge is characterized by rough stony and broken land and calcareous soil. The low flats in the north and northwest part of the area are covered by deep, fine-textured permeable soils.

Excessive runoff is caused in part by sparse vegetation and lack of soil cover. Vegetation has been reduced by drouth and overgrazing. Steep-walled arroyos are incised into formerly level alluvial plains. This severe down-cutting is widespread and has scarred the lowlands throughout the area. Cultivation is minor in the Eagle Mountains and vicinity, occurring only on the flood-plain of the Rio Grande.

LEAD, ZINC, COPPER, AND SILVER

In the Eagle Mountains, two adits (K.7–14.4) have been driven into a hill composed of the Precambrian Carrizo Mountain Formation. They explored veins of copper, zinc, and silver minerals just south of the large east-west Rhyolite fault. No positive record of production or shipment of ore is available (Gillerman, 1953, pp. 52–53).

A shallow shaft (M.3–14.3) was sunk in the northeastern part of section 48, block 68, T. 9, near the mouth of Spar Valley, to exploit copper mineralization along a small fault. Appoximately five tons of copper ore were shipped from this prospect in the early 1920's.

Lead, zinc, copper, and silver minerals occur at the Black Hills deposit (M-9) (Dick Love mine) northwest of the mouth of Snowline Canyon on the southwest side of the Eagle Mountains. Underground workings at the mine are said to be extensive; two shafts and an adit are visible at the surface. Small shipments of ore were reported from the deposit in 1922 and 1923.

The Silver Eagle lead and silver deposit (M-9), just southeast of the Black Hill deposit, was discovered in 1940. The U. S. Bureau of Mines trenched, drilled, and sampled the deposit for zinc in 1943–1944. Two shafts were sunk along a vein, but no production from the deposit was recorded.

A largely filled shaft (M.7–10.3) east of the Silver Eagle deposit was sunk on a vein in a diabase dike. Minerals identified in the dump are galena, sphalerite, hemimorphite, chalcopyrite, calcite, and quartz (Gillerman, 1953, pp. 52–53).

In the Indio Mountains, most of the prospecting and mining have been in the vicinity of the Indio ranch headquarters. Purple Sage lead prospect (U.4–14.3) received the most attention, but no ore was ever shipped. The Black Diamond mine (T.6–15.3) explored, unsuccessfully, lead and copper mineralization in the conglomerate of the Yucca Formation about a mile southeast of the Indio ranch headquarters. Prospect pits and shafts abound in the vicinity of the Black Diamond mine. Most of them explored copper or manganese mineralization in the conglomeratic beds of the Yucca Formation.

FLUORSPAR

Fluorspar occurs widely in the Eagle Mountains as replacement and fissure deposits. Evans' (1946) report on these fluorspar deposits resulted in the later work of Gillerman (1953), who investigated the deposit for the U. S. Geological Survey. The following information is largely from Gillerman (1953, pp. 53–92).

Fluorspar was first produced in Texas in the Eagle Mountains in 1924 when 48 tons of ore were produced but not immediately shipped. Mining activity during the productive years, 1942–1950 inclusive, was centered in the Spar Valley area; during this period slightly more than 15,000 short tons were produced.

Other deposits in the general vicinity of Spar Valley, such as the one near Eagle Spring and the Rocky Ridge deposit (M-9) some 3.5 miles southwest of the mill site in Spar Valley, produced only small amounts.

A small flotation mill, with an original capacity of 50 tons per day, increased in 1948 to 80 tons per day, was completed in January 1945, and was used through 1950 in processing ore from the Spar Valley deposit. The mill has since been dismantled and shipped elsewhere.

Calcite, ankerite, quartz, and small amounts of pyrite, hematite, and limonite are associated with the fluorspar. Appreciable quantities of sulfide minerals and barite, both commonly associated with western fluorspar deposits, are absent. The fissure deposits occur chiefly along east-trending and northeast-trending faults in rhyolite, whereas the replacement deposits are in limestone and sandy limestone. Fault gouge and breccia have also been mineralized by replacement.

Reserves in the Spar Valley area are estimated at 50,000 tons of measured, indicated, and inferred ore, and those in the Rocky Ridge area at 37,000 tons. Other smaller deposits are estimated to total 20,500 tons. A total of more than 100,000 tons of fluorspar ore containing a minimum of 30 percent CaF_2 is considered to be a conservative estimate of the reserves in the Eagle Mountains fluorspar deposit. Because all fluorspar deposits, with the exception of that near Eagle Spring, are near the Eagle Peak Syenite stock, the area within a 2-mile radius of the stock is the most promising for future prospecting. East-trending and northeast-trending faults and associated subparallel faults within this zone should be carefully examined as well as limestone beds similar to those in Spar Valley that have been partly replaced by fluorspar.

BARITE

Barite crops out (T.0–13.1) on the Bramblett ranch approximately half a mile east of the point at which Arroyo Escudo enters the low foothills along the western margin of the Indio Mountains, approximately 4 miles S. 40° W. from Squaw Peak. The barite occurs in the dark red-brown sandstone and chert-pebble conglomerate of the Yucca Formation, which strikes N. 25° E. and dips 20° to 35° NW. At one locality, barite appears to be a fracture filling 5 to 6 feet wide along a fault trending S. 35° E. Nearby, thin stringers of barite occur in sandstone of the Yucca Formation for 40 to 50 feet along strike.

PETROLEUM

There appear to be possibilities of petroleum production from the map area because of the volume and type of sedimentary rock therein. The stratigraphic section, which thickens drastically southwestward into the Chihuahua trough away from the Diablo Platform, offers the possibility of a petroliferous Pennsylvanian and Permian section at prospectable depth. Other Paleozoic rocks may be present. The Permian limestone in the Eagle Mountains is fossiliferous and characterized by a strong petroliferous odor on fresh surface.

The Cretaceous rocks cannot be ignored. Although the relatively thin Cretaceous section that crops out on the Platform is largely non-petroliferous, a test drilled at the western edge of the Platform (Brice's Fee No. 4) found free oil in the Buda Limestone. Furthermore, the Chispa Summit Formation contains bituminous strata that might serve as source beds in the subsurface. There is approximately 1,600 feet of black shale at the base of the Chispa Summit Formation just a few miles southwest of the map area.

The best area in which to test the Cretaceous and Paleozoic section is Red Light Valley between the Eagle Mountains—Indio trend and the Quitman Mountains to the west. This valley is the part of the map area farthest from the Diablo Platform. Thick Cretaceous and Paleozoic formations may underlie it.

Southwestward in the Chihuahua trough, Jurassic strata may occur subjacent to Cretaceous strata. The lower part of the Jurassic Malone Formation in the Malone Mountains northwest of Sierra Blanca consists of limestone conglomerate, impure limestone, sandy shale, and thin-bedded sandstone; the upper part, of black limestone with sandy beds near the top (Albritton, 1938, p. 1754). This somewhat clastic section is a fossiliferous near-shore facies, but farther south it probably changes to a deeper water facies. About 10 to 11 years ago, a 700- to 900-foot well drilled for water in Cedar Canyon, on the east flank of the southern Quitman Mountains, had a showing of gas sufficient to set off a flurry of leasing activity. Interest died almost immediately, however.

COAL

Thin beds of coal containing a very low percentage of uranium occur in the Eagle Spring area in steeply dipping black shale of the Chispa Summit Formation. Coal was probably first mined at this locality late in the 19th century, and the main operations were in Coal Mine Arroyo about 0.7 mile southeast of Eagle Spring. Although still accessible to C. L. Baker in 1922, the shaft had caved and was inaccessible to Gillerman in 1944–

1946. He reported (1953, p. 53) that the workings consisted of a shaft 200 feet deep with drifts at 100 and 200 feet, and that the last attempt to work the deposit was in 1927.

In 1959 the old, nearly filled shaft (then less than 6 feet deep) and a dump of coal tailings were the principal surface indications of former operations. A 30- to 40-foot shaft, clearly more recently worked, is 2,000 feet east-northeast of the older shaft.

REFERENCES

Adams, G. B. (1953) Stratigraphy of southern Indio Mountains, Hudspeth County, Texas: Univ. Texas, M. A. Thesis, 64 pp.

Adkins, W. S. (1933) The Mesozoic systems of Texas, *in* Sellards, E. H., et. al., The geology of Texas, Vol. 1, Stratigraphy: Univ. Texas Bull. 3232 (Aug. 22, 1932), pp. 239-518.

Albritton, C. C. Jr. (1938) Stratigraphy and structure of the Malone Mountains, Texas: Bull. Geol. Soc. Amer., vol. 49, pp. 1747-1806.

Baker, C. L. (1927) Exploratory geology of a part of southwestern Trans-Pecos Texas: Univ. Texas Bull. 2745, 70 pp.

Bostwick, D. L. (1953) Structural geology of northern Indio Mountains, Hudspeth County, Texas: Univ. Texas, M. A. Thesis, 56 pp.

Braithwaite, Phillip (1958) Cretaceous stratigraphy of northern Rim Rock Country, Trans-Pecos Texas: Univ. Texas, M. A. Thesis, 95 pp.

Bridges, L. W., II (1958) Revised Cenozoic history of northern Rim Rock Country, Trans-Pecos Texas: Univ. Texas, M. A. Thesis, 74 pp.

Carter, W. T., et al. (1934) Soil survey [reconnaissance] of Trans-Pecos area: U. S. Dept. Agric., Ser. 1928, no. 35, 66 pp., map.

DeFord, R. K. (1958) Tertiary formations of Rim Rock Country, Presidio County, Trans-Pecos Texas: Texas Jour. Sci., vol. 10, pp. 1–37. Reprinted as Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 36.

——— and Bridges, L. W., II (1959) Tarantula Gravel, northern Rim Rock Country, Trans-Pecos Texas: Texas Jour. Sci., vol. 11, no. 3, pp. 286–295.

Evans, G. L. (1946) Barite deposits in Texas *and* Fluorspar in Trans-Pecos Texas, *in* Sellards, E. H., et al., Texas mineral resources: Univ. Texas Pub. 4301 (Jan. 1, 1943), pp. 105–111.

Flawn, P. T. (1953), *in* King, P. B., and Flawn, P. T., Geology and mineral deposits of pre-Cambrian rocks of the Van Horn area, Texas: Univ. Texas Pub. 5301, pp. 27–69, 133–147, 177.

——— (In press) Precambrian rocks of south-central United States, *in* Rankana, K., The Precambrian, vol. 4, Interscience Publishers, New York, N.Y.

Gillerman, Elliot (1953) Fluorspar deposits of the Eagle Mountains, Trans-Pecos Texas: U. S. Geol. Survey Bull. 987, 98 pp.

Hay-Roe, Hugh (1957) Geology of Wylie Mountains and vicinity, Culberson and Jeff Davis counties, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 21.

——— (1958) Geology of Wylie Mountains and vicinity, Trans-Pecos Texas: Univ. Texas, Ph.D. Dissertation, 226 pp.

Huffington, R. M. (1943) Geology of the northern Quitman Mountains, Trans-Pecos Texas: Bull. Geol. Soc. Amer., vol. 54, pp. 978–1048.

King, P. B. (1953), *in* King, P. B., and Flawn, P. T., Geology and mineral deposits of pre-Cambrian rocks of the Van Horn area, Texas: Univ. Texas Pub. 5301, pp. 71–121, 125–133.

Richardson, G. B. (1904) Report of a reconnaissance of Trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23 (Min. Surv. Ser. 9), 119 pp.

Smith, J. F., Jr. (1940) Stratigraphy and structure of the Devil Ridge area, Texas: Bull. Geol. Soc. Amer., vol. 51, pp. 597–638.

——— (1941) Geology of the Eagle Spring area, Eagle Mountains, Hudspeth County, Texas: Field and Lab., vol. 9, no. 2, pp. 70–79.

Strain, W. S. (1959) Blancan mammalian fauna from Rio Grande Valley, Hudspeth County, Texas: Bull. Geol. Soc. Amer., vol. 70, pp. 376–378.

Taff, J. A. (1891) The Cretaceous deposits of El Paso County: Texas Geol. Survey 2nd Ann. Rept. (1890), pp. 714–738.

Twiss, P. C. (1959a) Geology of Van Horn Mountains, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map No. 23.

——— (1959b) Geology of Van Horn Mountains, Texas: Univ. Texas, Ph.D. Dissertation, 234 pp.

Underwood, J. R., Jr. (1962) Geology of Eagle Mountains and vicinity, Trans-Pecos Texas: Univ. Texas, Ph.D. Dissertation, 560 pp.