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TO ACCOMPANY MAP—GEOLOGIC
QUADRANGLE MAP NO. 39

GEOLOGY OF SOUTHERN QUITMAN MOUNTAINS, HUDSPETH COUNTY, TEXAS

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ILLUSTRATIONS

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INTRODUCTION

The Quitman Mountains are part of a narrow mountain range that extends southeastward from near Sierra Blanca, Texas (85 miles southeast of El Paso, Texas) into northern Mexico. The range is typical of many desert mountains of the southwestern United States in that it projects abruptly above the breached bolsons that border it. Thus the Quitman Mountains stand in stark contrast topographically and geologically to the Hueco Bolson on the west and the Red Light Bolson on the east.

Quitman Gap (also called Quitman Canyon, Quitman Pass, and Cañon de los Lamentos) divides the range into northern and southern parts. The northern Quitmans, composed of Tertiary intrusive and volcanic rocks with intensely folded Cretaceous rocks exposed around the periphery of the igneous mass, extend about 10 miles north-northwest from Quitman Gap to Interstate Highway 10. The southern Quitman Mountains, composed primarily of intensely folded and thrust-faulted Cretaceous rocks, extend from Quitman Gap south-southeast to the Rio Grande (a distance of about 25 miles). The elevation of the range gradually diminishes southward from about 6,600 feet above sea level in the northern part to slightly less than 4,000 feet above sea level near the Rio Grande. The maximum local difference in elevation is about 2,000 feet.

The highlands of the area studied are horsts flanked by grabens that are partly filled with sediment eroded from the mountains to form intermontane basins. The block faulting that created the horst and graben system followed the igneous activity and was superimposed on the earlier Laramide folds, thrust faults, and strike-slip faults characteristic of the Chihuahua tectonic belt.

The Cretaceous rocks exposed in the southern Quitman Mountains consist of about 14,000 feet of marine shale, sandstone, and limestone and nonmarine sandstone and shale. The lower 3,000 to 4,000 feet of the sequence are nonmarine rocks. Volcanic rocks overlie truncated folds in the Cretaceous sequence and consist mostly of tuffs, welded tuffs, and andesite.

The bolsons are filled by relatively undisturbed Tertiary and Quaternary sediments that were deposited as interbedded fanglomerates and fine-grained lacustrine-playa deposits.

Taff (1891) described stratigraphic sections from the Quitman Mountains, Eagle Mountains, and the Sierra Blanca area. He divided the rocks exposed in the Quitman Mountains into the Trinity, Fredericksburg, Washita, and Eagle Ford Groups. He further divided the lower Trinity Group into the Quitman and Mountain beds and described measured sections of these units at Quitman Gap. Although Taff did not recognize that the rocks at Quitman Gap were overturned, his descriptions are good, and the two units he described are essentially those used in this report.

In 1897 and 1898 T. W. Stanton measured stratigraphic sections near Quitman Gap and at the south end of the range across Calvert Canyon. He established from the faunal sequence that the strata were overturned and his observations, which were published in Cragin's (1905) report, did much to clarify the structure and stratigraphy of the area.

Baker, in 1922, mapped a large part of Trans-Pecos Texas, and his reports (1927, 1934) give a general description of the stratigraphy and show the geographic location and trend of the major structural features in the region. Baker (1927) recognized that the Quitman Mountains are part of a nearly recumbent anticline that has been thrust faulted. He divided the Cretaceous rocks of the Comanche Series exposed in the southern Quitman Mountains into the traditional Trinity and Fredericksburg Groups of Central Texas. Mistakenly he assigned the Cox and Finlay Formations to the Trinity Group.

Adkins (1933) gave an excellent summary of the stratigraphy of the area, corrected Baker's errors in the stratigraphic relations, and correlated the rocks exposed in the Quitman Mountains with strata in other parts of Trans-Pecos Texas and northern Mexico.

Scott (1940) published a stratigraphic section of the Trinity strata measured near Indian Hot Springs at the south end of the Quitman Mountains and correlated this section with one measured by Burrows (1909) near Cuchillo Parado, Chihuahua, Mexico. Scott, borrowing part of Burrows' nomenclature, divided the Trinity Group into the Las Vigas, Cuchillo, and Glen Rose Formations and correlated the ammonite zones of the strata with those recognized in Europe.

Huffington (1943) included a small part of the southern Quitman Mountains in his report and map of the northern Quitman Mountains. Albritton and Smith (1965) included that part of the present map area north of latitude 31° N. in their map and report of the Sierra Blanca area. Milton (1964) mapped the Cajoncito area along the Rio Grande, and Bell (1963) included a part of the bolson in his map and report. Campbell (1968) has made a detailed petrologic study of the Mountain Formation in the area.

This map and text are an abridgment of doctoral dissertations by Jones (1968) and Reaser (MS.). Reaser's dissertation is concerned primarily with stratigraphy and Jones' dissertation is concerned primarily with the structural geology of the area. The writers, however, share equal responsibility for the interpretations of the data and the validity of the conclusions.

The unpublished theses maps of Bell (1963) and Milton (1964), graduate students from The University of Texas at Austin, cover a small part of the map area along the Rio Grande. Their work on the west side of the southern Quitman Mountains is incorporated in the present map with only minor changes. These changes were made so that formation names and contacts would be consistent both in the Cajoncito area and in the southern Quitman Mountains.

The writers express their appreciation to Travis J. Parker, Texas A&M University, and Ronald K. DeFord, The University of Texas at Austin, for valuable assistance during the preparation of this report. Keith P. Young, The University of Texas at Austin, and J. Dan Powell, The University of Texas at Arlington, identified the ammonites. Bob F. Perkins, Louisiana State University at Baton Rouge, identified the rudistids and sponges. A Sigma Xi RESA Grant-in-Aid of Research provided part of Reaser's field expenses.

STRATIGRAPHY

Sedimentary rocks exposed in the Quitman Mountains area range in age from Cretaceous to Holocene. Figure 1 is a composite columnar section showing the gross lithology of the Cretaceous rocks of the southern Quitman Mountains area.

Deposits of probable late Tertiary and early Quaternary age fill the basins on either side of the mountains and are covered over large areas by more recent accumulations of alluvium, colluvium, and windblown sand. Volcanic rock of probable Tertiary age crops out in the Cajoncito area and in the southeastern part of the area mapped.

CRETACEOUS STRATA

The thickest sequence of Cretaceous rocks that crop out in Texas is in the southern Quitman Mountains. The nearly 14,000 feet of Cretaceous strata range in age from Neocomian(?) to Turonian. The deposition of these Cretaceous rocks appears to have been almost continuous. Changes in composition within the sequence are probably the result of fluctuations of the shoreline during the general northeastward advance of the Cretaceous sea from the Chihuahua Trough onto the Diablo Platform. The exposed Cretaceous succession was subdivided, from oldest to youngest, into the following nine formations: Mountain, Quitman, Cox, Finlay, Benevides, Espy, Eagle Mountains, Buda, and Ojinaga. This nomenclature is essentially the same as that applied by Underwood (1962, 1963) in the Eagle Mountains area except for the use of Mountain, Quitman, and Ojinaga Formations rather than Yucca, Bluff, and Chispa Summit Formations. For mapping convenience, some formations were subdivided into informal unnamed members. These members were mapped where boundaries are clear and persistent.

MOUNTAIN FORMATION

The Mountain Formation (Taff, 1891, pp. 730-732) consists of approximately 5,400+ feet of predominantly nonmarine sedimentary rocks. The base is not exposed in the Quitmans and the unit may be thicker than the section exposed at Quitman Gap (5,390 feet measured by D. H. Campbell, 1968). At most localities the exposed thickness of the unit ranges from 1,800 to 2,200 feet. The formation is exposed continuously from Indian Hot Springs on the south to Quitman Gap at the north end of the area and forms the western flank of the southern Quitman Mountains. The formation is also exposed in Mexico for a distance of about 1 mile south of Indian Hot Springs and in an area that extends 2 miles north of Quitman Gap. Farther south in Mexico these rocks form the main part of Sierra del Alambre, and north of Quitman Gap they abut against the Quitman intrusive mass.

On the basis of gross lithology the Mountain Formation is subdivided into three members. Although the three units differ in gross lithology, the boundaries occur in gradational sedimentary sequences and therefore were not mapped.

Lower member.—The exposed thickness of this member is 670 feet at Quitman Gap (Campbell, 1968). The base of the unit is covered, however, and its total thickness is not known. The lower member is exposed at only two places. One locality is in Quitman Arroyo at the west side of Quitman Gap; the other locality is in an unnamed arroyo about 2 miles south of Quitman Gap. At both places the unit is composed of buff thin-bedded, slightly clayey limestone, calcareous thin-bedded sandstone, and red, calcareous mudstone. A few green calcareous nodules are present in the mudstone. Charophyte remains occur at several horizons in the member.

The lower member of the Mountain Formation is tentatively correlated with the Navarrete Formation in El Cuervo area.

Middle member.—The middle member of the Mountain Formation is composed of red, light gray, and green sandstone, red mudstone, and red and gray shale. Most of the red sandstones are quartz-cemented and hard; the light gray sandstones are calcite-cemented and surficially friable. Limestone-pebble conglomerates are present throughout the member but are not abundant. These conglomerates occur as channel fills and either pinch out or grade laterally into sandstone. Other conglomerates, composed of red, gray, and black chert, and white and pink vein quartz pebbles, occur also as channel fillings. The chert-pebble conglomerates are generally from 1 to 2 feet thick and can rarely be traced more than 100 feet; a single 9-foot bed crops out south of Red Bull Spring. Conglomeratic sandstone is present but not abundant. The general pattern of sedimentation in the member is cyclic; conglomerate and sandstone plus the overlying red mudstone constitute a cycle. The basal beds of a

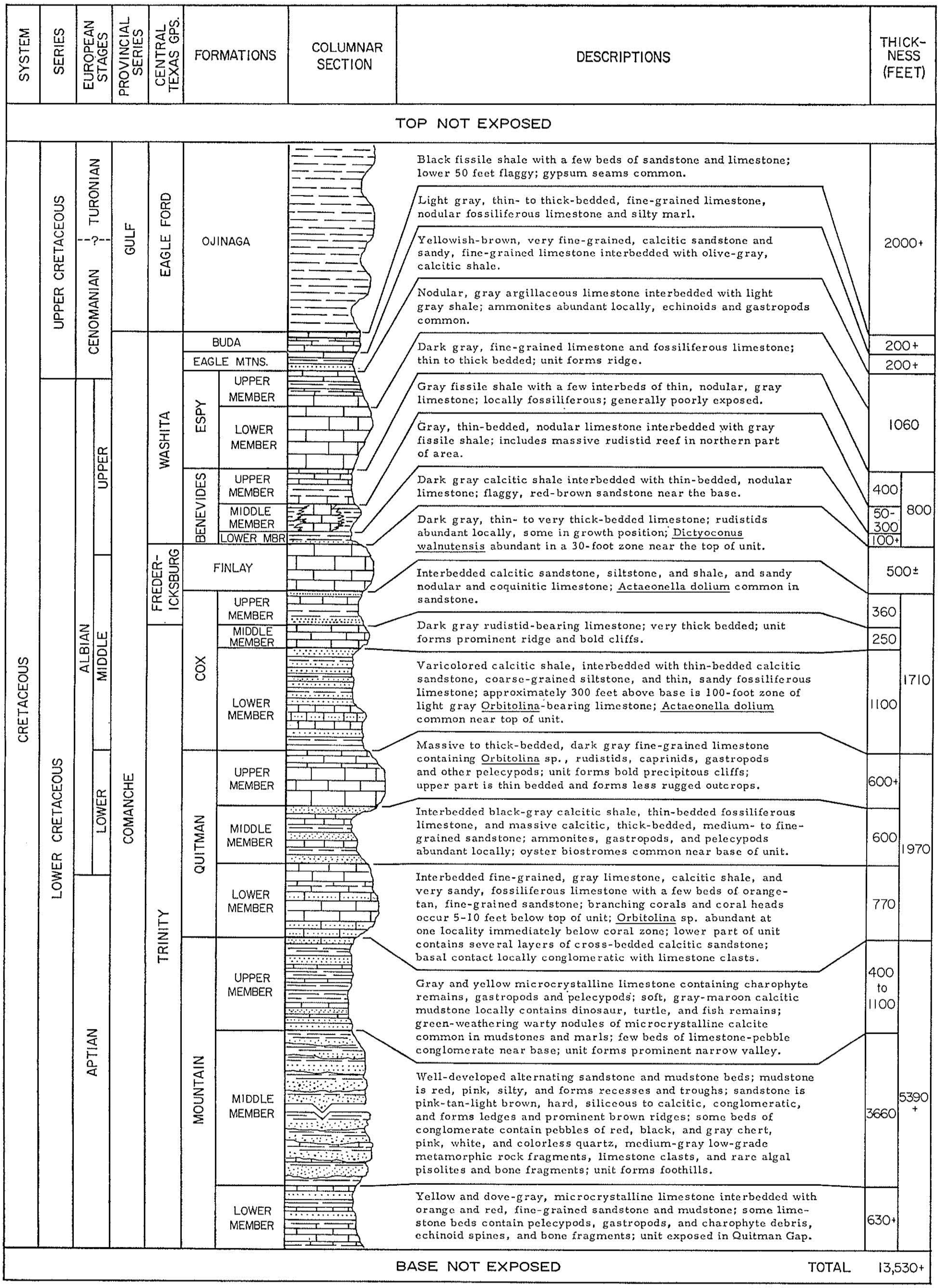

FIG. 1. Cretaceous stratigraphic section in the southern Quitman Mountains area.

cycle commonly truncate the mudstone of the underlying set.

The middle member of the Mountain Formation is lithically similar and probably correlative with the Las Vigas Formation.

Upper member.—The upper member of the Mountain Formation is composed of thin-bedded sandstone, black and gray marl, thin-bedded limestone, and a few beds of limestone-pebble conglomerate. Carbonate rocks make up more than 50 percent of the sequence. An abundance of irregularly shaped limestone nodules, most of which are stained light green or encrusted by hard, grayish-brown clay, occur in the marl.

Orange-yellow-weathering, fine-grained limestone and marl in the upper member of the formation contain charophyte gyrogonites and smooth-shelled ostracods. The gyrogonites closely resemble the widely distributed Cretaceous form *Atopochara trivolvis* Peck. Reaser (MS.) found reptilian bone fragments in the upper member of the formation about a quarter of a mile south of the Rio Grande, near Indian Hot Springs. These bone fragments were identified by Wann Langston (personal communication, 1963) as probably from ornithischian dinosaurs. Campbell (1968) reported vertebrate fossil remains at approximately the same stratigraphic level at several places in the southern Quitman Mountains.

Grayish-red and light brown silicified wood is abundant at approximately the same stratigraphic level as the vertebrate remains. Some petrified logs are as much as 18 inches in diameter and 9 feet long. Silicified wood fragments seem to be more abundant south of the Red Bull fault zone than north of the zone.

The upper part of the Mountain Formation is vertically gradational in gross aspect into the overlying Quitman Formation. The contact between the Quitman and Mountain Formations is arbitrarily placed at the base of the first thick-bedded, cross-bedded calcareous sandstone above the thin-bedded marl and limestone of the Mountain Formation.

There has been some controversy about the thickness of the Mountain Formation in the Quitman Mountains. Taff (1891, pp. 730-731) measured 4,080 feet of rock in the Mountain Formation near Quitman Gap. Baker (1927, p. 20) stated that about 2,000 feet of the strata in Taff's measured section is repeated by folding. Other geologists, in private conversations, have also maintained that the Mountain Formation cannot be as thick as reported by Taff. However, Huffington (1943) measured more than 5,500 feet of the Yucca Formation at Quitman Gap which included Taff's "Mountain bed" and found no evidence of repetition of the section. Albritton and Smith (1965) also found no evidence for the repetition of beds by folding at Quitman Gap.

Campbell (1968) measured 5,390 feet of the Mountain Formation in the Quitman Gap area and found no evidence of structural repetition of the strata. The writers have closely examined the strata exposed at Quitman Gap and could find no evidence for the repetition of beds. The beds in the Quitman Gap section are near vertical or overturned; all overturned beds dip to the southwest. If the section were repeated by folding, then at least one limb of the fold would have to be normal, but this is not the case. Consequently, the sequence is not repeated by folding. There is a possibility that the unit could be repeated by a strike fault, but no evidence for large-scale faulting has been found.

Baker, as well as other geologists working in the area, probably based the argument for folding on the ostensible repetition of the upper member.

Beds of finely crystalline limestone that weather orange yellow and contain charophyte gyrogonites occur both above and below the middle member of the formation at Quitman Gap. Campbell (1968) has studied these rocks in detail and stated that the units are not the same. R. E. Peck (personal communication, 1964) examined gyrogonites from the two units and stated that they were not the same species. He also reported that the gyrogonites from the lower unit are older than those in the upper unit. Thus there is strong evidence against the interpretation that the section is repeated.

Charophyte gyrogonites indicate the age of the upper member of the formation is Aptian. No definite statement concerning the age of the rest of the unit can be made other than it is Early Cretaceous (Campbell, 1968). Campbell (1968) and Reaser (MS.) have suggested that the formation may contain strata as old as Neocomian, but at the present time there appears to be no direct evidence for this age assignment in the southern Quitman Mountains.

The upper member of the Mountain Formation is approximately 1,000 feet thick at Quitman Gap, 400 feet thick at Indian Hot Springs, and appears to be relatively thin a short distance south of the Rio Grande (Campbell, 1968). It is possible that the upper member of the Mountain Formation is lithically correlative with the upper part of the Las Vigas Formation in Mexico (fig. 2). P. W. Beckley (personal communication, 1961) suggested that the upper member was correlative with the lower part of Cuchillo Formation of Chihuahua, Mexico.

QUITMAN FORMATION

Taff (1891, pp. 728-730) applied the name "Quitman bed" to strata exposed on the eastern side of Quitman Gap. It is difficult, if not impossible, to determine the exact boundaries of Taff's "Quitman bed," but the Quitman Formation of this report includes essentially the same rocks as originally defined by Taff, plus the unit Taff called "Bluff bed" at Quitman Gap.

The Quitman Formation is divided into three lithically and topographically distinct members; the upper and lower members are composed of resistant limestone and are separated by a middle nonresistant shale member. The upper and lower members crop out almost continuously from the Rio Grande to Quitman

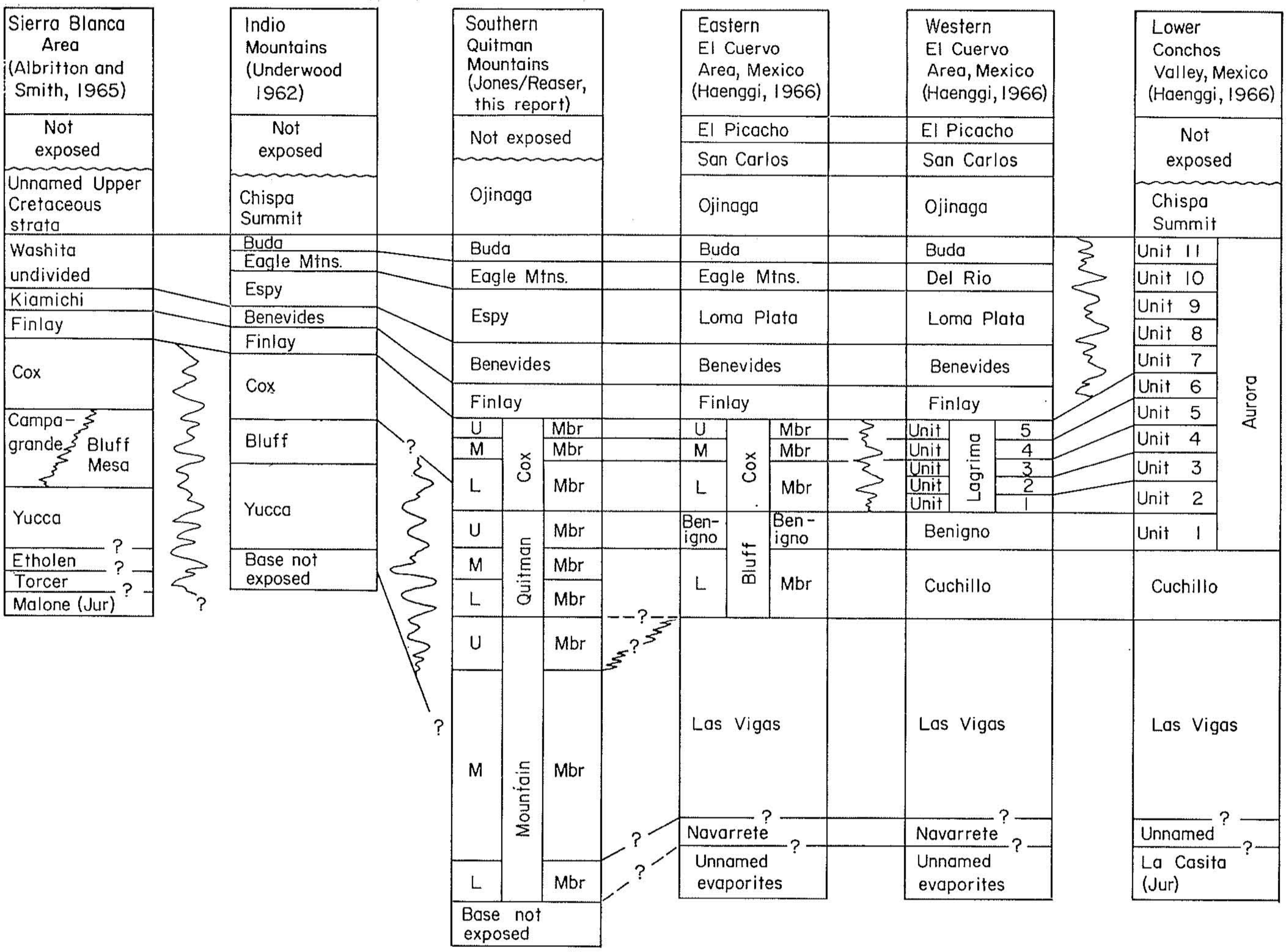

FIG. 2. Lithostratigraphic correlation of Cretaceous strata, Trans-Pecos Texas and Chihuahua, Mexico.

Gap and are well exposed at most places. The middle member is well exposed from the Rio Grande to the Red Bull fault zone, but north of the fault zone the middle member crops out only in the few arroyos that breach the formation. Despite excellent exposures, the formation is difficult to study because of its inaccessibility. A walk of several miles and a climb of 1,000 to 1,500 feet are nearly everywhere necessary to examine the formation. The only readily accessible and relatively undisturbed section of the Quitman Formation is along the Rio Grande east of Indian Hot Springs.

Lower member.—The lower member of the Quitman Formation is 776 feet thick at Indian Hot Springs (Jones, 1968). The unit is characterized by resistant, very thick-bedded, sandy, fossiliferous limestone, sandy oolitic limestone, and fine- to medium-grained, calcareous sandstone separated by nonresistant, thin-bedded, calcareous sandstone and siltstone, silty limestone and marl, and silty shale.

The lower half of the member is characterized by sandy fossiliferous limestone which generally forms small cliffs and short dip slopes. In addition to abundant oysters and oyster fragments the lower beds contain small, poorly preserved pelecypods and gastropods, and fragments of dark petrified wood. Oolitic calcareous sandstone and sandy oolite limestone containing abundant fossil fragments occur at several stratigraphic levels in the lower member. Cross-bedding is common in these beds.

The upper half of the lower member generally forms a shallow saddle along the crest of a ridge. The lower part of this sequence consists of hard, thin-bedded clayey, fossiliferous limestone interbedded with calcareous shale, and very fine-grained, calcareous sandstone. The upper part of the unit consists of fine- to medium-grained, yellowish-gray, calcareous sandstone. The sandstone weathers pale yellowish brown and grades vertically into thick-bedded, sandy, fossiliferous limestone that weathers pale yellowish brown.

Fossils are abundant throughout the lower member but are generally present as unidentifiable fragments. Biostromes composed primarily of *Exogyra quitmanensis*

Cragin are numerous in the upper part of the member. Other molluscs present include *Exogyra* sp., *Pecten (Neithea)* sp., *Trigonia* sp., *Turritella* sp., *Parahoplites* sp., and rudistids. Reaser (MS.) found the ammonite *Dufrenoya* sp. aff. *D. justinae* (Hill) in the upper part of the lower member in Mexico, and Scott (1940) reported it near the base of the lower member near Indian Hot Springs. *Orbitolina* sp. cf. *O. texana* Roemer occurs in profusion in the upper part of the middle member in Smugglers Gap but was not observed elsewhere in the member.

Colonial corals occur at several stratigraphic levels but are most abundant in the upper 20 feet of the lower member. Corals are present at several places throughout the length of the Quitman Mountains and in the Cajoncito area in the upper few feet of the member. The best exposure of the corals is in Mexico (Reaser, MS.) where a 4- to 6-foot zone of branching corals in apparent growth position is exposed.

Middle member.—The middle member of the Quitman Formation is well exposed along Mayfield Canyon, about 2 miles downstream from Indian Hot Springs. The member is also well exposed for about 2 miles along an unnamed canyon north of the Red Bull fault zone, but the structure of that area is too complex to permit the member to be easily studied there. Throughout most of the area the member forms a saddle between the resistant limestone members above and below it. Because the member is covered with soil or limestone float at most places, outcrops are scattered and poor.

The middle member consists of about 600 feet of nonresistant, fossiliferous, gray, calcareous shale interbedded with resistant thin- to thick-bedded, sandy, fossiliferous limestone, calcareous sandstone, and calcareous siltstone. Three resistant beds of very fine-grained sandstone form prominent ledges about the middle of the member at Indian Hot Springs. These resistant sandstones have not been identified in the northern part of the area.

At most localities it is not difficult to pick the boundaries of the middle unit because it is easily eroded and forms a prominent topographic break. The top of the unit is placed above the nonresistant clastic sequence at the base of the first massive limestone, which forms a 50- to 100-foot near-vertical cliff at most places. The base of the middle member is placed at the top of the last massive limestone in the carbonate sequence of the lower member. Where beds are in normal sequence, as in Mayfield Canyon, this limestone forms a dip slope.

The middle member of the Quitman Formation is very fossiliferous in the vicinity of Indian Hot Springs. Few fossils were found north of Mayfield Canyon. The ammonite fauna in Mayfield Canyon has been described in detail by Scott (1940); it includes five new genera and 19 new species of ammonites. Fossils characteristic of the member include *Exogyra quitmanensis* Cragin, *Ostrea* sp., *Pecten (Neithea)* sp., *Tapes* sp., *Trigonia* sp., *Hemiaster* sp., *Lunatia* sp., *Natica* sp., *Dufrenoya* sp., *Hypacanthoplites* sp., *Arctica* sp., *Cyprimeria* sp., and *Ctenostreon cumminsi* Stanton.

Upper member.—The thick, upper limestone member of the Quitman Formation is generally exposed as a 50- to 100-foot vertical cliff followed by a series of smaller 10- to 15-foot cliffs. The Buckhorn triangulation station is on the upper member; it overlooks a 300- to 400-foot cliff, the highest sheer cliff in the map area.

Reaser (MS.) measured about 600 feet of the upper member in an incomplete section immediately south of the study area in Mexico. Milton (1964, p. 20) measured a complete section of the upper member in the Cajoncito area where the unit is 590 feet thick.

The basal part of the unit is composed of dark gray limestone that weathers light gray. In Mayfield Canyon the lower limestone is massive and forms a 75-foot escarpment. The thickness of the lower limestone changes along strike and at many places it is only 10 to 15 feet thick. The overlying strata are resistant, medium-bedded to very thick-bedded, ledge-forming limestones interbedded with thin-bedded (2 to 5 inches) limestone, sandstone, and shale.

The basal limestone contains sparse to abundant *Orbitolina* sp. cf. *O. texana* Roemer, *Porocystis globularis* (Giebel), small terebratulid brachiopods, unidentified echinoids, small solitary corals, and rudistids. B. F. Perkins (personal communication, 1964) identified the rudist *Coalcomana* sp. in float near the base of the escarpment. Scott (1940, pl. 55) reported *Toucasia* and *Monopleura* from this massive limestone in Mayfield Canyon. The upper limestone sequence is characterized by an abundance of *Orbitolina* sp. cf. *O. texana* Roemer.

The upper member of the Quitman Formation appears to be lithically correlative with the Benigno member of the Bluff Formation and the Benigno Formation of Haenggi (1966) in El Cuervo area of Mexico. The lithic correlation of the middle and lower members of the formation with the lower part of the Bluff Formation and the Cuchillo Formation of Haenggi is less certain. The lower part of the Cuchillo may be correlative with the upper part of the Mountain Formation.

The age of the Quitman Formation is Late Aptian to late Early Albian. The formation is paleontologically correlative with the upper part of the Cow Creek Limestone, the Hensell Sandstone, and the lower and middle part of the Glen Rose Limestone of Central Texas.

COX FORMATION

The Cox Formation (Richardson, 1904, p. 47) is exposed in a narrow band along the eastern slope of the Quitman Mountains from the Rio Grande to Smugglers Gap. It is also exposed in a number of discontinuous outcrops between Smugglers Gap and Quitman Gap. Because the Cox Formation is a relatively nonresistant unit it is poorly exposed at most places. Throughout much of the area it occurs in a structurally complex area. The only locality where a structurally simple complete section of the Cox Formation may be studied is in an area extending south from Smugglers Gap for about 3 miles.

The exposed Cox section consists of interbedded sandstone and siltstone, limestone, and shale interrupted in the lower and upper part by two very thick-bedded, fossiliferous limestone sequences. The formation is readily divisible into three lithically distinct members, a lower clastic member, a middle carbonate member, and an upper clastic member. The upper and lower contacts are arbitrarily chosen and are probably not at the same stratigraphic position at any two localities. The lower contact is placed at the top of the stratigraphically highest limestone below the sandstone and shale sequence of the lower Cox Formation. The top of the formation is placed at the base of the first limestone above the sandstone and shale sequence of the upper member. Because there is a marked difference in the resistance to erosion of limestone and sandstone or shale, the contacts can generally be recognized more easily on aerial photographs than in the field.

Lower member.—The lower member of the Cox Formation is approximately 1,000 feet thick in the vicinity of Smugglers Gap (Jones, 1968). The member consists of interbedded calcareous shale, laminated and cross-laminated fine-grained sandstone, coarse siltstone and sandy fossiliferous limestone, but the percentage of sandstone increases from about 40 percent near the base of the unit to about 60 percent at the top. Some of the sandstones show current or oscillation ripple marks.

A 100±-foot carbonate sequence is present about 30 feet above the base of the member. This carbonate sequence is present throughout the area and served as an excellent marker bed. The lower part of the carbonate sequence is composed of massive limestone beds which generally form a low cliff and grade upward into thin-bedded nodular limestone. The upper part of the sequence is composed of interbedded gray calcareous shale and thin-bedded limestone. *Orbitolina* sp. cf. *O. texana* Roemer is abundant in most of the thin-bedded limestone. Green calcareous nodules occur in the shale at some places.

Fossils collected from the limestone include *Arctica* sp., *Exogyra* sp., *Pachymya* sp., *Pecten (Neithea)* sp., *Lunatia* sp., *Tylostoma* sp., and cerithid gastropods. *Actaeonella dolium* Roemer occurs at several horizons in the upper 300 feet of the unit at many localities in sandstone.

Middle member.—The middle member of the Cox Formation, which is 250 feet thick near Smugglers Gap, is composed of thick-bedded reef limestone containing abundant silicified rudistids at some places. Locally it has beds of rudistid limestone with rudistids in growth position. Although this unit forms prominent ridges or escarpments throughout the area, its thickness ranges from 110 feet in Mexico (Reaser, MS.) to 420 feet in the Cajoncito area (Milton, 1964).

Upper member.—The upper member of the Cox Formation is lithically similar to the lower member. Near Smugglers Gap the member consists of 366 feet of interbedded fine-grained calcareous sandstone and siltstone, sandy nodular limestone, fossiliferous limestone, and shale. Limestone composes about 40 percent of the total thickness with sandstone and shale comprising about equal amounts of the remaining thickness. *Actaeonella dolium* Roemer is common at many localities and at several stratigraphic levels in the unit. This taxon is most abundant near the top of the unit. The nodular limestone contains the ammonite *Engonoceras* sp., abundant *Exogyra texana* Roemer, *Tylostoma* sp., and fragments of unidentified fossils.

The age of the Cox Formation is late Early to Middle Albian. It is paleontologically correlative with the upper part of the Glen Rose Formation, the Paluxy Formation, and most of the Walnut Formation of Central and North Texas. The horizon equivalent to the Trinity-Fredericksburg contact in Central Texas is approximately at the top of the middle member of the Cox Formation.

FINLAY LIMESTONE

The Finlay Limestone (Richardson, 1904, pp. 47-48) forms a prominent ridge or escarpment in the area studied. Southeast of Smugglers Gap the Finlay Limestone forms the west wall of a strike valley. Northwest of Smugglers Gap it forms many prominent escarpments and in a few localities caps the east ridge of the Quitman Mountains. In the Cajoncito area the Finlay Limestone forms the narrow canyon that is referred to locally as "Cajoncito," or Little Box Canyon on the Rio Grande. The Finlay Limestone is about 500 feet thick near Smugglers Gap, 700 feet thick at the south end of the Quitman Mountains along the Rio Grande, and 590 feet thick at Cajoncito.

The formation consists of resistant, ledge-forming, very thick-bedded, fossiliferous limestones interbedded with slope-forming nodular limestone and silty calcareous shale. The shale is covered or poorly exposed at most places. The resistant beds are composed of fine-grained fossiliferous limestone. Coarse-grained, rudistid-shell material, stained by iron oxide at some places, is more resistant than the enclosing fine-grained limestone and stands out in slight relief on weathered surfaces. Irregularly shaped brownish masses of chert and cherty limestone are randomly distributed in some limestone beds.

The thick limestone beds have rough weathered surfaces that locally show solution features similar to those pictured by Smith and Albritton (1941, pls. 1 and 2) on beds of Finlay Limestone near Sierra Blanca. These solution features are well developed on most inclined limestone beds.

The upper part of the Finlay is characterized by the foraminifer *Dictyoconus walnutensis* (Carsey). The fossil is easy to identify because it is triangular shaped in a lateral section. It is so abundant at some places as to give the rocks a "freckled" appearance. Near Smugglers Gap the foraminifer is abundant in a 26-foot zone from 109 to 135 feet below the top of the formation. This fossil zone has been recognized throughout the area.

In addition to foraminifers and rudistids, the uppermost Finlay beds contain *Enallaster texanus* (Roemer), *Lunatia* sp. cf. *L. pedernalis* (Roemer), *Nerinoides* sp., *Protocardia texana* (Conrad), small bundles of resistant calcareous worm tubes, abundant turritellid gastropods, and unidentified solitary corals.

The term "Finlay Formation" has been applied to the thick-bedded limestone sequence of Middle Albian age throughout western Trans-Pecos Texas and northern Chihuahua, Mexico. It is one of the most uniform, easily recognized, and widespread units of the entire area.

The Finlay is paleontologically correlative with the Walnut, Comanche Peak, and Edwards Formations in Central Texas and the Walnut and Goodland Formations in North Texas.

BENEVIDES FORMATION

The Benevides Formation (Amsbury, 1959) crops out in an almost continuous band along the east side of the southern Quitman Mountains from Smugglers Gap southeastward to Cedar Well. The formation is also exposed in the Cajoncito and Goat Canyon areas.

The unit forms two different types of topographic features. In an area approximately 7 miles long by 2 miles wide between Smugglers Gap and Quitman Gap the formation is characterized by narrow strike valleys and low rounded hills. The escarpments are the result of a resistant massive reef limestone within an otherwise nonresistant shale and thin-bedded limestone unit.

Throughout most of the area the formation is covered by alluvium or float and is mapped as undifferentiated Benevides. However, in areas where the reef is present the formation is well exposed and can be subdivided into three topographic and lithic members. In places where the reef is present the formation is mapped as three separate members.

Lower member.—The lower member of the Benevides Formation consists of dark gray calcareous shale interbedded with thin-bedded, fine-grained calcareous sandstone, and thin-bedded nodular limestone. The member is generally covered by float or soil and is poorly exposed. West of the Wright ranch headquarters, an incomplete section includes from bottom to top: 30+ feet of gray fissile shale, 23 feet of interbedded nodular limestone and gray shale, and 8 feet of flaggy fine-grained calcareous sandstone that weathers red brown. The red-brown-weathering flaggy calcareous sandstone is a distinctive characteristic of the member and can be used to distinguish it from other shale sequences. The lower member of the Benevides Formation is very fossiliferous at a few localities. The following fauna was collected from the map area: *Exogyra texana* Roemer, *Trigonia* sp., *Pecten (Neithea)* sp. cf. *P. (N.) georgetownensis* Kniker, *Pecten (Neithea) irregularis* (Böse), *Paleopinna comanchensis* (Cragin), *Texigryphaea* sp., *Crassatellites* (?) sp., *Tylostoma* sp., *Enallaster* sp. cf. *E. texanus* (Roemer), *Manuaniceras* sp. cf. *M. supani* (Lasswitz), *Manuaniceras supani (Lasswitz), Engonoceras* sp.

Middle member.—The middle member of the Benevides Formation is predominantly a thick-bedded carbonate sequence.

Clifford Brown (personal communication, 1965) measured a 322-foot section of the member in an unnamed canyon about 1.5 miles northwest of the Wright ranch headquarters. This section consists of a basal unit of calcirudite, a middle unit of calcareous sandstone and sandy oolitic limestone, and an upper unit of sandy calcarenite. Although the thickness of the member varies, the general sequence appears to be uniform throughout the area of its occurrence. Caprinids or rudistids are abundant on bedding surfaces but are not visible on vertical sections because of recrystallization or the massiveness of the unit. Brown concluded, however, that they are present throughout the section and that the middle member is a caprinid reef.

Upper member.—The upper member of the Benevides Formation consists of gray fissile shale with a few interbeds of thin nodular gray limestone. At a few localities the member is fossiliferous. This member is rarely exposed because it is easily eroded and is covered at most places by alluvium. A part of the unit is well exposed on the east side of the strike valley south of the Wright ranch headquarters.

The fauna of the upper member includes *Holaster simplex* (Shumard), *Enallaster texanus* (Roemer), *Macraster* sp., *Pecten (Neithea) texana* (Roemer), *Exogyra texana* (Roemer), *Drakeoceras* sp. cf. *D. lasswitzi* Young, *Mortoniceras* n. sp., *Oxytropidoceras stenzeli* Young, *Beaudanticeras* sp., *Idiohamites fremonti* (Marcou), *Ophryoceras* sp., *Craginites serratescens* (Cragin).

The base of the Benevides Formation is covered in most places by colluvium, but where exposed it appears to be conformable with the Finlay Formation. The lower contact is placed at the top of the last massive limestone in the Finlay carbonate sequence. The upper member of the Benevides is transitional into the lowermost Espy Formation; nonresistant fissile shale and nodular limestone grade vertically into resistant thin-bedded limestone and fissile shale. The Benevides-Espy contact is placed at the base of the first massive limestone above the nodular limestone and shale sequence. This limestone generally marks a prominent topographic break that is readily apparent on aerial photographs as well as in the field.

Ammonites indicate that the age of the Benevides is Late Albian. Paleontologically the formation is correlative with the Kiamichi and Duck Creek Formations of North Texas (Young, 1959, fig. 4, p. 758). A horizon equivalent to the Fredericksburg-Washita boundary in Central Texas is probably the Finlay-Benevides contact.

ESPY LIMESTONE

The Espy Limestone (Huffington, 1943, p. 1006, amended by Underwood, 1963, p. 9) forms a group of low foothills and hogback ridges along the central and southeastern parts of the southern Quitman Mountains. The northernmost exposure of the formation is a low hill about 200 yards south of the Dogie Wright ranch headquarters. The best exposure of the Espy Limestone is in the canyon of the Rio Grande through the southern Quitman Mountains.

The Espy Limestone has been divided into two topographically distinct members: an upper slope-forming member composed of thin- to thick-bedded limestone with interbedded shale and a lower ridge-forming member composed of thin- to thick-bedded limestone with interbedded marl and shale.

Lower member.—The lower member of the Espy Limestone consists of thin- to thick-bedded limestone with marl and shale interbeds. The basal part of the lower member is composed of nodular limestone in beds 6 inches to 1 foot thick interbedded with dark fissile shale in layers 2 to 4 inches thick. The upper part of the lower member consists of thin- to thick-bedded, resistant, ledge-forming limestone interbedded with less resistant, slope-forming, nodular limestone and marl. Some of the resistant limestone layers are tens of feet thick, but when traced laterally, they divide into irregularly bedded strata that range from less than 2 feet to more than 6 feet thick.

The lower member of the Espy Limestone contains the following fossils: *Texigryphaea washitaensis* Hill, *Mortoniceras* sp., *Pecten (Neithea)* sp., *Pedinopsis* sp., *Pervinquieria* sp., *Plicatula* sp., *Protocardia*(?) sp., *Tetragramma*(?) sp., *Turritella* sp., *Tylostoma* sp., and a large unidentified oyster.

Upper member.—The upper member of the Espy Limestone consists of resistant, thin- to thick-bedded, fossiliferous limestone interbedded with less resistant, nodular limestone, flaggy sandy limestone, and calcareous shale. At places where the formation is overturned, the lower member forms a steep slope. The sequences of nodular limestone weather to 1- and 2-inch nodules that produce treacherous "ball-bearing" slopes. Abundant iron oxide nodules, some of which consist of limonite pseudomorphic after pyrite, are scattered over most outcrops.

The upper member of the Espy contains *Plesioturrilites brazoensis* (Roemer), *Paracymatoceras texanum* (Shumard), *P. loeblichi* Miller and Harris, *Ostrea subovata* (Shumard), *Haplostiche texana* Conrad, *Exogyra arietina* Roemer, *Texigryphaea graysonana* (Stanton), *T.* sp., *Lima* sp., *Pecten (Neithea)* sp., *P. (N.) texana* Roemer, *Plicatula* sp., *Trigonia* sp., *Hemiaster* sp., *Holectypus charltoni* Cragin, and unidentified bryozoans and corals.

Based primarily on ammonites, the age of the Espy is Late Albian to Early Cenomanian. Paleontologically, it is correlative with the Georgetown Limestone of Central Texas and with part of the Duck Creek and the Fort Worth, Denton, Weno, Pawpaw, and Main Street Formations of North Texas. The upper part of the Espy in the map area is probably lithically and faunally equivalent to the lowermost part of the Del Rio Formation in the vicinity of Del Rio, Texas and the Grayson Formation in North Texas.

EAGLE MOUNTAINS FORMATION

The red- to brown-weathering Eagle Mountains Formation (Gillerman, 1953, pp. 27-29) is the most colorful Cretaceous formation in the area. Its distinctive outcrop band is easily recognized and traced in the field and on aerial photographs. The formation crops out in the foothills along the east edge of the Quitman Mountains and in the Mule Canyon—Calvert Canyon vicinity.

The Eagle Mountains Formation consists of 200 to 300 feet of fissile, greenish-gray, calcareous shale with subordinate interbedded flaggy, red to brown, calcareous sandstone and sandy limestone. The red color is the result of the weathering of included iron-bearing minerals.

The lower part of the formation contains abundant *Haplostiche texana* (Conrad) on the upper surface of some flaggy beds. Generally, the tests of this uniserial foraminifer are randomly oriented but at some places, Cedar Well, for example, the tests appear oriented by currents.

In addition to *Haplostiche texana* (Conrad), the Eagle Mountains Formation contains the following fossils: *Faraudiella* n. sp., *Graysonites* sp. cf. *G. adkinsi* Young, *Graysonites* sp., *Exogyra cartledgei* Böse, *Camptonectes* sp., *Turritella* sp., *Texigryphaea* sp., *Pecten (Neithea)* sp., *Plicatula* sp., and *Protocardia* sp.

The formation contacts are generally covered or poorly exposed. The upper contact is placed at the base of the first massive limestone above the nonresistant clastic sequence of the Eagle Mountains Formation; the lower contact is at the top of the first thick limestone bed below the nonresistant clastic sequence.

The age of the Eagle Mountains Formation is Early Cenomanian. It is paleontologically equivalent to the Del Rio Formation of Southwest Texas and northern Mexico and to the Grayson Formation of North Texas.

BUDA LIMESTONE

The Buda Limestone (Vaughan, 1900, p. 18) crops out in a series of ridges and low hills north of Cedar Well and is widely distributed along the Rio Grande on the southeast side of the southern Quitman Mountains. The formation ranges in thickness from about 200 feet in the Cedar Well area to about 350 feet along the Rio Grande.

The Buda Limestone is divisible into three members but these members were not mapped. The upper and lower members are composed of resistant massive limestone; the middle member is a nonresistant nodular limestone. The gray limestone of the Buda is lithically similar to the limestone of the Espy Limestone; because of this similarity, identification of the formation in poorly exposed, isolated outcrops or in intensely folded areas is difficult.

Lower member.—The lower member of the Buda is a prominent ridge-former and consists of thin- to thick-bedded, porcelaneous, fossiliferous limestone. It is characterized by the disk-shaped ammonite *Budaiceras,* which occurs throughout the formation but is most abundant in the lower part.

The lower member yielded the following fossils in the Love Station vicinity: *Budaiceras evae* (Lasswitz), *B.* sp. cf. *B. evae* (Lasswitz), *B.* sp. cf. *B. elegantior* (Lasswitz), *B.* n. spp., *B. hyatti* (Shattuck), *B.* sp. aff. *B. hyatti* (Shattuck), *Faraudiella roemeri* (Lasswitz), *F.* sp. cf. *F. roemeri* (Lasswitz), *F.* sp. cf. *F. franciscoensis* (Kellum and Mintz), *F. texanum* (Shattuck), *Sharpeiceras* sp. aff. *S. tlahualiloense* (Kellum and Mintz), *Turrilites* sp., *Paracymatoceras* sp. cf. *hilli* (Shattuck), *Ostrea (Arctostrea)* sp. cf. *O. carinata* Lamarck, *Texigryphaea* sp., *Lima* sp., *Pecten (Neithea)* sp., *Hemiaster calvini* Clark, *H.* sp., *Turritella* sp., worm tubes, small solitary corals, unidentified foraminifers and gastropods.

Middle member.—The middle member of the Buda Limestone consists of interbedded gray limestone, marl, and calcareous shale that generally forms a topographic saddle between prominent ridges of limestone. Resistant thin-bedded limestone and blocky limestone are separated by partly covered intervals of thin-bedded nodular limestone, silty marl, and silty calcareous shale. Iron oxide nodules, similar to nodules in the Eagle Mountains Formation and in the upper member of the Espy Formation, are common in the blocky beds and are scattered over most of the covered areas.

Siliceous sponges are abundant in the middle member in the map area but are sparse in the lower and upper members. The sponge material is usually preserved as a fragmentary cellular network in the rock, but some well-preserved, more nearly complete individuals have been found. B. F. Perkins (letter to D. F. Reaser, July 30, 1962) identified *Eurete* sp. from Buda Limestone in the area near the Rio Grande.

In addition to abundant sponges, foraminifers, and ostracods, the middle member of the Buda contains *Budaiceras* n. sp., *B.* spp., *Paracymatoceras* sp., *Pecten (Neithea)* sp., *Protocardia* sp., *Hemiaster calvini* Clark, *Pleurotomaria (Leptomaria)* sp., a caprinid, and numerous fossil fragments.

Upper member.—The upper member of the Buda Limestone consists of thin- to thick-bedded limestone and generally forms a prominent ridge. Locally some thick beds contain a thin, light to moderate brown, siliceous fretwork that stands in slight relief on weathered surfaces. This resistant framework resulted from the deposition of chalcedonic chert in numerous fine fractures in the rock. A few cherty nodules, about 2.5 inches in longest dimension, are also present in the limestone.

The top of the Buda is placed at the top of the last massive limestone of the carbonate sequence. The contact is easily recognized because the base of the overlying unit is nonresistant flaggy limestone and shale and forms a pronounced topographic as well as lithic break.

The Buda of late Early Cenomanian age is present in the subsurface of South and East Texas and extreme northeast Mexico. Baker (1927, p. 13) first applied the term "Buda Limestone" to limestone in the map area and surrounding region. Because it is traceable from the type locality in Central Texas to West Texas as a nearly continuous rock body (Brand and DeFord, 1958, p. 56), the formation name is used in this report.

The Buda is the uppermost formation of the Washita Group; its top probably coincides with the boundary between the Comanche Series and Gulf Series throughout northern Mexico as in Central, South, and West Texas.

OJINAGA FORMATION

The Ojinaga Formation (Burrows, 1909), youngest Cretaceous formation in the area, consists of more than 2,000 feet of shale and sandstone with subordinate amounts of limestone, dolomite, and siltstone. It is lithically similar to part of the Benevides Formation in the area and is distinguished from the Benevides by fossil content and by stratigraphic position. The formation is well exposed along the Rio Grande in the Calvert Canyon —Mule Canyon area and in Mexico. The lower 200 to 300 feet of the formation is exposed in an unnamed arroyo north of Cedar Well.

Although the Ojinaga Formation was mapped as a single unit it can be subdivided on the basis of differences in gross lithology and marker beds. The units used in this report are a lower flaggy unit, a middle shale unit, and an upper sandstone and shale unit.

The lower unit of the Ojinaga Formation conformably overlies the Buda Limestone. This unit is 75 feet thick and consists of thin-bedded, argillaceous, flaggy limestone interbedded with dark fissile shale and a few thin beds of friable calcarenite in the lower part. A few dark gray limestone concretions also occur in the unit.

In addition to foraminifers, unidentified oysters and plant fragments, the lower unit contains the following fossils: *Inoceramus* sp., *Corax* sp., *Encodus* sp., *Ptychodus* sp., *Desmoceras (Pseudouhligella) elgini* Young, *Euhystrichoceras adkinsi* Powell, and *Pseudacompsoceras bifurcatum* Powell.

The middle unit consists of fissile shale, thin-bedded limestone, a few beds of sandstone, and 1-inch thick layers of gypsum and limonite. Finely disseminated pyrite and pyrite nodules are common in the dark shale. The number of sandstone beds increases toward the top of the unit. Three "marker" beds occur in the member, and they greatly facilitate mapping geologic structures in the unit or in subdividing the unit as Powell (1961) and Reaser (MS.) have done.

The middle "marker" bed contains *Acanthoceras calvertense* Powell, *A.* sp. aff. *A. hippocastanum* (J. Sowerby), *Mammites nodosoides* (Schlotheim), *Pseudaspidoceras flexuosum* Powell, *Vascoceras* sp., *Fagesia haarmanni* Böse, *Pachyvascoceras compressum* (Barber), *P. globosum* Reyment, *Allocrioceras* sp., *Quitmaniceras brandi* Powell, *Quitmaniceras reaseri* Powell, and *Inoceramus labiatus* (Schlotheim).

The uppermost "marker" bed is a 1-foot sandstone bed that contains many fossiliferous limestone concretions. This bed yielded the following fossils: *Coilopoceras* sp., *Mammites? depressus* Powell, *M.* sp., *Neoptychites gorguechoni* Pervinquiere, *N. xetriformis* Pervinquiere, *Romaniceras* sp., *Selwynoceras mexicanum* (Böse), *Spathites rioensis* Powell, *Inoceramus labiatus* (Schlotheim), entwined colonial molluscs possibly *Teredolites* sp., and a fossil fish identified by J. A. Wilson (personal communication, 1960) as *Syllaemus* (?) sp.

The upper unit of the Ojinaga Formation consists of interbedded sandstone, sandy and silty shale, and thin sandy limestone containing abundant fragments of *Ostrea* sp. The lower part of this unit is exposed at only a few places in the area, and the uppermost part of the unit is exposed only in Mexico about a mile southwest of the Bob Love Crossing on the Rio Grande.

Based on ammonites, the age of the Ojinaga Formation in the map area is Early Cenomanian through early Turonian (Powell, 1961, p. iii). The uppermost part may be as young as late Santonian or possibly Campanian (Reaser, MS.). The lower part of the Ojinaga is paleontologically correlative with the Eagle Ford of Central Texas and the Chispa Summit of West Texas and northern Mexico and is in part correlative with the Boquillas of West Texas and northern Mexico.

CENOZOIC STRATA

The oldest unit of probable Cenozoic age in the area mapped is boulder conglomerate exposed in Calvert Canyon. This conglomerate is overlain by volcanic rocks which crop out in the southeastern part of the area and in the Cajoncito area. Dikes and sills of igneous rock occur at a few localities in the southern Quitman Mountains and are probably about the same age as the volcanic rocks. A thick section of sedimentary rocks overlies the volcanic sequence and fills the Hueco and Red Light basins on the east and west sides of the mountain range. The basin fill was mapped as one unit. There is considerable vertical and horizontal variation in the lithology of this sedimentary sequence; however, the relations of these lithologic changes are not well enough known to warrant subdivision of the unit at the present time. Three terrace gravels are younger than the basin deposits. Alluvium, colluvium, and windblown sand are present throughout much of the area and make up the youngest deposits.

BOULDER CONGLOMERATE

A conglomerate exposed at the north end of Calvert Canyon unconformably overlies folded shale of the Ojinaga Formation. The only good exposure of the conglomerate is along a small unnamed arroyo that intersects the Calvert Canyon road. Exotic boulders, similar to those composing the conglomerate, strewn on high ridges in the area suggest that the bed once had a greater areal extent.

The conglomerate consists of reworked Cretaceous material ranging in size from granules to boulders embedded in a clay and sand matrix. It contains virtually every rock type characteristic of the local Cretaceous stratigraphic section with the possible exception of soft, fissile shale.

The conglomerate contains no recognizable volcanic rock fragments; therefore, it was probably deposited before vulcanism in the area.

VOLCANIC ROCKS

A 600-foot thick sequence of volcanic rocks crops out in the southern part of the Quitman Mountains. About 15 square miles of the area are presently covered by volcanic rocks, but scattered remains of these rocks near Indian Hot Springs and in the bolson east of the mountains, as well as in the Cajoncito area, suggest that much of the Quitman Mountains area was once covered by these rocks. They include ignimbrites, tuffs, and flows.

The volcanic rocks overlie an erosional surface which truncates folded Cretaceous rocks. In Calvert Canyon, the lower ignimbrite overlies the boulder conglomerate at some places and Cretaceous strata at others. Along the west side of Mayfield Canyon and at many other places, the middle ignimbrite rests unconformably on Cretaceous strata. The general northwest-southeast trend of the exposed volcanic rocks and the apparent thinning of the sequence northeast and southwest of this trend suggest that the volcanic sequence filled a strike valley eroded primarily in the Ojinaga Formation.

Lower ignimbrite.—The oldest volcanic unit exposed in the map area is a composite layer of ignimbrite, which forms a prominent, west-facing cliff and dip slope on the east side of Calvert Canyon. The ignimbrite is divided into a lower, dark gray to black, vitric welded tuff and an upper, grayish-red, lithic welded tuff. These two units plus the overlying lower tuff probably comprise a genetic cooling unit and reflect a decrease in the temperature of formation vertically upward.

The lower, 9-foot, glassy tuff is covered at most places, but it is exposed at places along the base of the cliff by small prospect pits. In hand specimen the lower tuff resembles a pitchstone, but in thin section, arcuate and branching devitrified ghosts of glass shards and lack of stratification indicate that the rock is a glassy ignimbrite.

The resistant upper welded tuff is distinctly foliated with folia that bend around and between inclusions and contains angular and rounded volcanic and sedimentary inclusions and calcite amygdules. At most places the upper unit forms a dip slope.

Lower tuff.—The lower ignimbrite is overlain by nonfoliated sandy tuff, tuff, and tuff breccia along the east side of Calvert Canyon. The gray, sandy tuff, 100+ feet thick, is very fine grained, thin bedded and cross-bedded. It is partly opalized at some levels in the lower part. A few beds in the lower part are bentonitic and exhibit a "crackled" appearance on a dry weathered outcrop. This unit includes a lens of conglomerate composed of fragments of volcanic and sedimentary rock which is well exposed in a small gully east of the Calvert Canyon road and east of the westernmost volcanic ridge. At most places the sandy tuff is either covered or has been removed by erosion.

Gray, pink, or blue tuff and tuff breccia conformably overlie the sandy tuff. The breccia, composed of clasts of volcanic rocks, is more massive than the sandy tuff, especially near the top. The clasts range up to 2.5 cm long and are embedded in a glassy matrix. Thin layers of minutely fractured, brownish-black and pale red perlite occur at some levels. The rough outcrop is pitted and has small caves at the top.

Middle ignimbrite.—Along the north rim of Goat Canyon and the northeast rim of Calvert Canyon, the tuff breccia is overlain by a composite ignimbrite (100+ feet thick). Throughout much of the area, however, this ignimbrite overlies Cretaceous rocks. It is divided into a lower, resistant, cliff-forming unit and an upper, less resistant unit. The lower resistant unit, which forms a prominent, vertically fractured cliff at most places, is characterized by elongate, secondary vein-fillings. At an outcrop west of Indian triangulation station, there is a basal glassy tuff that is several feet thick, but it cannot be traced laterally more than a few hundred feet. The upper surface resembles an autobreccia with the autoliths up to 1.5 inches long.

The less resistant upper unit is distinctly thinly laminated and weathers to a porous, friable rock. Walking on it produces a characteristic "crunch," like walking on cinders. It can be identified almost as well audibly as visually.

Middle tuff.—Aphanitic tuff and tuff breccia overlying the middle ignimbrite are highly variable lithically and difficult to trace laterally. Much of the aphanitic tuff is well indurated and has a subconchoidal fracture. A bed of laminated red tuff crops out on the east side of Calvert Canyon. This tuff appears to be cross-bedded and may be fluvial. Pink tuff breccia containing volcanic rock fragments and numerous crystals, mostly bipyramidal, crops out locally. Unless the rock is a fluvial breccia, the double terminated quartz crystals indicate a higher temperature of formation for the breccia than that of most of the volcanic rocks in the map area. The tuff and tuff breccia are exposed only in the Calvert Canyon vicinity; they are either not present or not exposed elsewhere. Because of the small area of outcrop, the unit is not shown on the geologic map.

Andesite.—Tuff and tuff breccia are overlain by red to grayish-brown andesite. The andesite is characterized at some places by numerous spherical to elongate, filled and unfilled vesicles that range from less than 0.5 mm to more than 10 cm long. Most of the cavities are filled with grayish-yellow calcite amygdules that weather pale greenish yellow, but some contain biscuit-shaped, layered-quartz amygdules that enclose botryoidal quartz and large calcite crystals interlaced with a dark metallic mineral, possibly a manganese mineral.

Large amygdules are abundant in only a few small areas; the basal part of the andesite is scoriaceous at some places. Ingerson (1953, fig. 2, p. 1059) showed the distribution of amygdaloidal areas in the andesite. He suggested that the vesicles were probably filled by low-temperature, hydrothermal solutions. He also suggested that the locations of the areas of amygdules were controlled by jointing near faults or shear zones.

Trachyte porphyry.—About 20 feet of resistant, greenish-gray, trachyte porphyry overlies the andesite at a few places in the Calvert—Mule Canyon area. The light greenish cast of the rock that is evident on fresh exposure and in thin section appears to result from finely disseminated riebeckite(?) in the rock matrix. The weathered trachyte is stained brown to desert-varnish black at most places. Dark metallic specks are disseminated throughout the rock at most places. Alkali feldspar phenocrysts, mostly anorthoclase, range up to 4.5 mm long. The scale of the map precludes the inclusion of this unit on the geologic map.

Upper tuff.—Soft pink tuff and white tuffaceous clay form a slight slope between the andesite and the upper ignimbrite. The pink tuff is about 12 feet thick and is easily eroded. Pods of hard pink tuff contain fluorescent opal in a few places. About 2 feet of thinly laminated and cross-laminated, white, tuffaceous clay underlies the pink tuff at one locality. X-ray analysis of the clay indicates that it is calcium montmorillonite. The tuff and tuffaceous clay, like the trachyte porphyry, are either not present or not exposed in most of the area. The unit is not shown on the geologic map.

Upper ignimbrite.—The most widespread volcanic layer in the area is a composite ignimbrite that is well exposed at a number of places on the east side of Calvert Canyon and in several canyons north of the Babb ranch headquarters.

The upper ignimbrite can be divided into four units which grade vertically one into the other. A hard, 5-foot, volcanic breccia (probably a flow breccia) marks the base of the unit and is composed of light brownish-gray and pale red-purple, angular, volcanic rock fragments. Some of the autoliths are fragments of laminated welded tuff up to 2 inches long. The breccia is overlain by about 2 feet of slightly porphyritic rhyolitic, welded tuff that is horizontally banded brown and gray. The banded tuff grades upward into unbanded, light gray tuff of a similar composition.

The uppermost part of the upper ignimbrite is similar in color and composition to the two underlying units, but it is more resistant and weathers brownish gray and desert-varnish black. The brownish-gray tuff caps many low hills with the light gray tuff exposed on the slopes. The uppermost unit is highly jointed with brown staining along the fractures. A faint banding is visible at some places. Feldspar phenocrysts, although badly fractured, appear to have euhedral outlines in hand specimen, but in thin section most of the phenocrysts are rounded and enveloped by an alteration rim.

Basalt remnants.—There are isolated remnants of basalt south of the Indian Hot Springs road and southeast of Indian triangulation station. These widely scattered remnants are probably the youngest volcanic rock in the area mapped. Ingerson (1953, p. 1063) suggested that a thick basalt flow capped the volcanic sequence in the southern Quitman Mountains but has been "completely removed or the remnants are buried under the alluvium to the east." All the basalt occurs as float covering other volcanic units; therefore, the relative age and distribution of the unit can only be estimated. The fact that basalt float occurs on top of hills capped by upper ignimbrite suggests that the basalt is younger than the other volcanic units.

The similarity of individual volcanic rock layers and of homotaxial sequences in the Rim Rock country and the southern part of the Quitman Mountains suggests a genetic and temporal relationship between these volcanic successions. Although the distance (about 50 miles) between the two areas would make a layer-for-layer correlation tenuous, the volcanic rocks in the map area are probably correlative with the Vieja Group of the Rim Rock country and the intervening volcanic rock sequence in the Indio Mountains.

No fossils were found in the volcanic sequence in the map area, but volcanic rock in the Indio Mountains and Rim Rock country, east of the map area, provides an indication of the approximate age. Vertebrate remains recovered from the Vieja Group (Wilson, 1965, table 9, p. 34) range in age from late Eocene to early Oligocene. The K-Ar age is about 35 m.y. (Wilson, 1966, p. 229). The vertebrate remains from the Indio Mountains also indicate a late Eocene to early Oligocene age for the volcanic rock sequence in that area (Underwood, 1962, p. 237).

R. E. Denison (letter to Reaser dated January 17, 1970) reported that a K-Ar age of about 35 m.y. was obtained from sanidine phenocrysts in the middle and upper ignimbrites in the southern Quitman Mountains. Phenocrysts of sanidine from quartz trachyte porphyry exposed in the same area ranged in age from 30.5 to 32.9 ± 0.6 m.y. The isotopic age and recent field observations by Reaser suggest that this porphyry may be intrusive.

SEDIMENTARY ROCKS

The Cenozoic sedimentary sequence consists of fluvial, lacustrine, colluvial, and eolian deposits. The fluvial and lacustrine deposits which fill the Hueco and Red Light Bolsons are overlain by terrace gravel at some localities. The youngest sediments include colluvium, windblown sand, and alluvium along the arroyos.

Bolson fill.—Although the bolson fill (QTb) is not differentiated on the geologic map, these deposits consist of a complex sequence of intergrading and intertonguing fluvial and lacustrine sediments. Albritton and Smith (1965, p. 92) concluded from their investigations of the Hueco Bolson that the bolson fill consists of three intergrading and intertonguing facies. These three facies are (1) conglomerate, (2) interbedded sandstone, siltstone, and clay, and (3) gypsiferous clay. Exposures of the bolson fill east and northeast of the Neely ranch headquarters clearly show the relationship of these three facies.

The conglomerate facies is composed primarily of poorly sorted, angular to subangular pebbles and cobbles. There are boulders up to 4 feet in diameter near the mountains. Bedding in the conglomerate is indistinct at most localities, but lenses 1 to 3 feet thick of well-sorted, bedded and cross-bedded sandstone and poorly sorted pebbly sandstone occur throughout the sequence. The conglomerate was deposited as coalescing alluvial fans extending into the basins and their composition was determined by the outcrops in the adjacent highlands. Rock fragments of all resistant formations in the map area have been identified in the unit. In addition to the lateral variation in composition there is also a vertical variation in the composition of the conglomerate facies. The conglomerate at the base of the unit is composed almost entirely of volcanic rock fragments. The percentage of volcanic rock fragments decreases in overlying conglomerate, and the youngest conglomerate is composed entirely of sedimentary rock fragments except near existing outcrops of volcanic rocks.

The sand-clay facies consists of interbedded friable calcareous sandstone, siltstone, and light brown calcareous clay and silty clay. The clay is reddish brown and partly silty or sandy; most layers are massive but some are evenly bedded and finely laminated.

The gypsiferous clay facies consists of interbedded clay, silt, gypsum, and gypsiferous clay and fine-grained sandstone. Calcareous gypsiferous clay is the principal constituent. It is reddish brown, greenish gray, or almost white and occurs in beds that are finely laminated to massive. The reddish-brown and greenish-gray beds alternate and give many outcrops a banded appearance. Selenite crystals are scattered through the gypsiferous clays and in places are concentrated to form whole beds.

The bolson fill (QTb) of the Hueco and Red Light Bolsons is lithically similar to valley fill in other parts of Trans-Pecos Texas, New Mexico, and northern Mexico. However, many of these intermontane basins were closed drainage basins during the deposition of the fill, and a lithic correlation of individual units between basins is difficult if not impossible.

The age of the bolson fill has not been determined precisely but it probably ranges from late Tertiary to early Quaternary. Strain (1959; 1966, p. 24) found vertebrate fossils of Pleistocene age in alluvium overlying the bolson fill (QTb) near McNary, Texas, 20 miles northwest of the map area. Basal beds of bolson fill are composed almost entirely of volcanic rock fragments; thus the fill must be younger than the volcanic rocks (late Eocene to early Oligocene) and older than the alluvium (early Pleistocene).

Terrace and pediment gravel.—Thin layers of gravel unconformably overlie beveled bolson fill in some parts of the map area. Where exposed, the base of the gravel is an irregular, broadly undulating surface of erosion. An individual gravel layer produces a relatively smooth, gently sloping upper surface that represents a temporary base level of streams tributary to the Rio Grande. In some highly dissected areas, only isolated, gravel-capped hills remain of the former broad surfaces.

The gravels on three ancient surfaces differing in elevation above the Rio Grande flood-plain were mapped as separate units. The oldest and highest terrace (Qgl) is preserved at only a few localities. The best preserved terrace (Qg2) is extensively developed in both the Hueco and Red Light Bolsons.

Gravel that could not be included with confidence in the established gravel-capped terraces because of poor development, small areal extent, or uncertain stratigraphic position, was mapped as undifferentiated terrace gravel (Qg).

Alluvium and colluvium.—Recent alluvium, widespread along the flood-plain and stream-bed deposits of present streams, except the Rio Grande, is mapped as Qal 1. The flood-plain of the Rio Grande lies below the flood-plain of most of the tributary streams and is mapped as Qal 2.

Colluvium is best represented adjacent to topographically higher features in the map area. It includes slope wash deposits, soil creep deposits, talus, and some thin alluvial deposits (Albritton and Smith, 1965, p. 100). At some places, a thin caliche layer has developed on the colluvium.

Windblown sand.—Light brown sand overlies bolson fill and terrace gravel at several localities along the Rio Grande. The dunes generally border the flood-plain of the Rio Grande and are active or only partially anchored by vegetation. The sand is probably less than 12 feet thick at most places and appears to be reworked flood-plain deposits. Large numbers of arrowheads and other artifacts have been found in dune areas near Indian Hot Springs (Wayne Babb, personal communication, 1964) but have not been reported from the other dune areas.

TECTONIC SETTING

Two structural elements, a relatively stable structural platform and a mobile geosynclinal belt, dominated the tectonic framework of Trans-Pecos Texas and northern Mexico during the latter part of the Mesozoic Era and the early part of the Cenozoic Era (fig. 3). These two elements are the Diablo Platform and the Chihuahua Trough.

The Diablo Platform was uplifted during the late Paleozoic orogeny that culminated during the early part of the Permian Period. The platform was exposed from the time of its development until it was inundated by the eastward and northeastward advance of the Cretaceous sea during Albian time. Erosion of the emergent platform probably provided the clastic material for the Lower Cretaceous sediments deposited in the adjacent Chihuahua Trough to the west and southwest. Cretaceous strata overlying the platform are generally thin and are composed predominantly of carbonate rock that has been only slightly disturbed by structural deformation.

The Chihuahua Trough probably developed at the same time as the Diablo Platform. It has been in existence at least since Late Jurassic time. Sedimentary rock of Jurassic age is exposed in the Malone Mountains of Texas and in northern Chihuahua. A thick sequence (14,000+ feet) of Jurassic and Cretaceous sedimentary rocks accumulated before the Laramide orogeny ended deposition in the trough. The structural belt that resulted from the deformation has been referred to as the Chihuahua tectonic belt (DeFord, 1958, pp. 72, 74). It was formed contemporaneously with the deformation of the Sierra Madre Oriental of central Mexico, and it may be a branch of the Sierra Madre.

The Chihuahua tectonic belt is a complex system of northwest-trending, strongly folded, mountain ranges in northern Chihuahua, Mexico, and southern Hudspeth County, Texas. Some of these folded ranges are more than 100 miles long.

The southern Quitman Mountains are along the northeastern border of the Chihuahua tectonic belt. In this range as in other ranges in the eastern part of the tectonic belt, thrusting, overturning, and asymmetry of folds are eastward or northeastward toward the Diablo Platform.

Reaser (MS.) has pointed out the similarity between folds in the Quitman Mountains area and those of the Jura Mountains of Europe and the High Atlas Mountains of northern Africa. Many of the small folds of the area resemble the knickfolds of Pierce (1966, p. 1267) from the Jura Mountains.

Although overturned folds and thrust faults are considered "typical" of the Chihuahua tectonic belt, the present physiographic features were produced during the Tertiary by normal faults that created a series of fault blocks. The uplifted blocks were eroded to form the present mountain ranges, and the depressed blocks have been partly filled with detritus to produce the present bolsons. The map area lies within and near the northeast margin of the Chihuahua tectonic belt and near the eastern margin of the Basin-and-Range province.

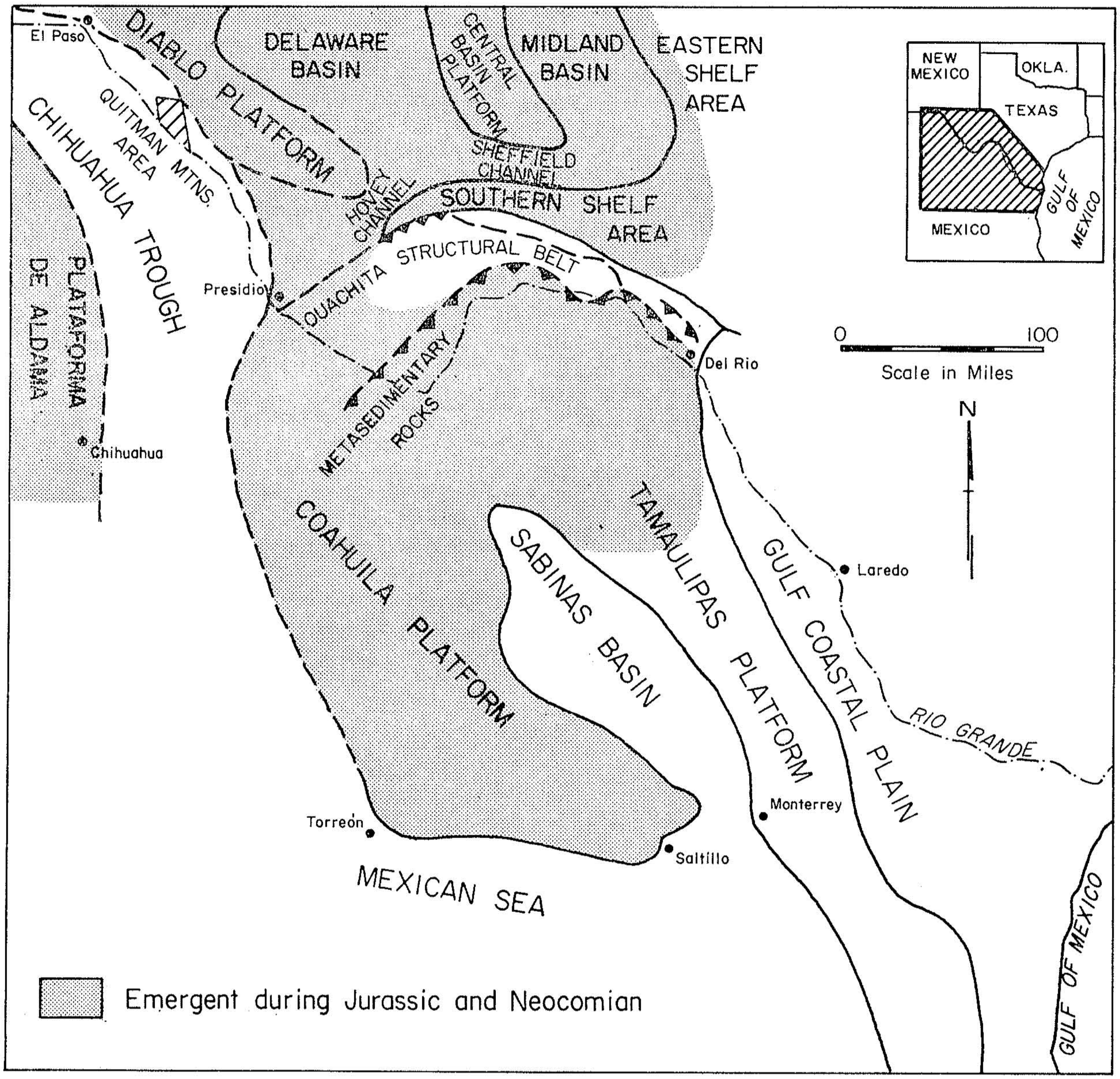

FIG. 3. Late Paleozoic and Mesozoic tectonic features, Trans-Pecos Texas and northeastern Mexico. After Haenggi (1966, p. 135).

STRUCTURAL GEOLOGY

INTRODUCTION

Locally, the structure of the Cretaceous strata of the Quitman Mountains is extremely complex, but on a large scale the structure of these rocks can be described as a block-faulted, thrust-faulted, nearly recumbent anticline and syncline. The mountains may be a tilted fault block rather than a simple horst. The west side of the Quitman Mountains is bounded by a normal fault, but evidence for a normal fault on the east side of the mountains is inconclusive.

In addition to post-Laramide block faults, the folds are cut by a thrust fault and at least two sets of normal or strike-slip faults.

FOLDS

The Cretaceous rocks exposed in the southern Quitman Mountains are roughly divided into three parallel structural zones. From west to east these zones are: (1) the east limb of an overturned (nearly recumbent) anticline, (2) an overturned syncline, and (3) a belt of smaller folds east of the overturned folds. Superimposed on these large folds is a group of minor folds. Thus, there are three orders of magnitude of folds within the area: major, intermediate, and minor.

MAJOR FOLDS

Quitman anticline.—The Quitman Mountains are part of a northwest-trending overturned anticline. Erosion and faulting have removed the west limb of the anticline in the map area. The east limb and parts of the crest of the fold are exposed in the mountain range. Reaser (MS.) proposed the name "Quitman anticline" for this fold and that term is used in this report.

The anticline can be traced south of the Rio Grande for about 15 miles where the fold is covered by bolson fill without any indication of plunging (Reaser, MS.). It can also be traced north of the map area for about 2 miles where it abuts against the northern Quitman intrusive mass. Thus, the anticline is continuous for approximately 40 miles, being offset only by cross faults. The Cretaceous rocks exposed in the Quitman Mountains north of the igneous intrusion, and those in the Malone Mountains still farther north, may form a continuation of the Quitman anticline. If this supposition is correct, the Quitman anticline is at least 60 miles long. The southern Quitman Mountains then would be only a part of a much larger structural feature.

Throughout much of the length of the mountain range all or part of the beds of the eastern limb are overturned to the northeast. In some places overturned beds have been rotated more than 180° by minor folding or drag along normal faults. Overturning is recognized by inverted faunal successions as well as by the presence of inverted oscillation ripple marks, mud cracks, cross-bedding, and other sedimentary structures. The attitude of these beds indicates that the axial surface of the anticline is, as expected, warped. The general southwest dip of the axial surface ranges from almost horizontal to about 30 degrees.

Within the map area the anticline is broken by a major tear fault (Red Bull fault zone), a thrust fault (Quitman thrust), and numerous minor faults.

Calvert syncline.—The term Calvert syncline is applied to the northwest-trending complex fold adjacent to the Quitman anticline east of the mountain range.

Throughout much of its length the syncline consists of a short inverted limb (shared with the Quitman anticline) and a long, normal northeast limb (Sections A-A′, D-D′, and E-E′). Both limbs of the fold are well exposed in the Calvert Canyon area and in the Benevides strike valley south of Smugglers Gap. North of Smugglers Gap the syncline is concealed beneath the thrust plate of the Quitman anticline. About 4 miles south of Smugglers Gap the trend of the syncline changes from northwest to approximately east-west and cuts across the strike of the Espy, Eagle Mountains, and Buda Formations to form a part of the complex Warden Station fold area. It appears that the axis of the syncline may have been deflected eastward in this area by drag along the Red Bull fault zone.

Warden Station fold area.—One of the most complexly folded areas in the southern Quitman Mountains, and certainly one of the most difficult to interpret, covers approximately 2 square miles in the vicinity of the Warden triangulation station. This area, called the Warden Station fold area, is bounded on the south and west by the outcrop of the Espy Formation and on the east by bolson deposits. The folding becomes less complex toward the north where the area merges with the Love Station fold belt.

The major problem in the area is not in identifying the units involved, which are the Buda, Ojinaga, and Eagle Mountains Formations, but rather in determining whether the formations are overturned or normal. Sedimentary features, such as filled cavities, worm burrows, and cross laminations, were inconclusive, and at most places it was never determined with any degree of certainty whether the rocks were normal or inverted.

Near Warden Station steeply dipping limestone beds of the Buda crop out in an area two-thirds of a mile wide and 2 miles long. Because the Buda Limestone is only about 200 feet thick and most of the beds dip in the same direction, a normally folded sequence cannot explain the thick sequence of exposed limestone. Two other factors that must be taken into account are the overturned beds that form the west rim of the area and the normal sequence that occurs both to the east and north of the area. A structural interpretation of these beds indicates the presence of a syncline overturned to the north-northeast. The folds in the normal sequence are on the normal limb of the overturned syncline and are a part of the Love Station fold belt.

A partial solution to the problem of attitude of the beds is furnished by cross laminations in a few outcrops of brown siltstone. These cross laminations indicate that some of the beds are in normal position. At a few places thin slivers of the Ojinaga Formation, 10 to 30 feet thick, are present between successive ridges of Buda Limestone. Cross laminations in some of these outcrops indicate the beds are overturned. Unfortunately, at no single locality were both normal and overturned beds observed. Therefore, all that can be said with any degree of certainty is that both normal and overturned beds occur in the area. Any structural interpretation must, however, account for the presence of both.

The simplest explanation of the structure is a normally faulted overturned syncline in which the Ojinaga Formation has either been faulted out by thrust faulting or squeezed out by the intense folding.

The interpretation chosen here is that thrust faulting plays no significant role in this area. This conclusion is based on the fact that in localities where the Buda Formation is continuous and can be traced from overturned to normal sequence, in other words, a plunging overturned syncline, most of the Ojinaga Formation is missing and yet the Buda Limestone has not been cut by thrust faulting (Section C-C′). This implies that the Ojinaga Formation was squeezed out. The interpretation used in mapping this area, then, was that the Ojinaga Formation was squeezed out of the center of an overturned syncline, so that overturned Buda Limestone was allowed to rest almost directly on normal Buda that had already been folded. The folds were later cut by normal or strike-slip faults to give the present outcrop pattern.

INTERMEDIATE FOLDS

Exposures along the eastern edge of the Quitman Mountains indicate that the beds of the long, normal, northeastern limb of the overturned Calvert syncline have been deformed but the intensity of deformation was much less than that which formed the overturned anticline and syncline (Sections A-A′, B-B′, and D-D′). This belt of folds is continuous from Quitman Gap to Cedar Well where it is covered by bolson fill or volcanic rocks. The folds are also exposed over a large area in the vicinity of Love triangulation station. This belt of folds has been called the Love Station fold belt (Jones, 1968; Reaser, MS.). It and other parts of the Quitman Mountains are currently being exhumed by streams tributary to Red Light Draw.

Within the map area the Love Station fold belt is characterized by broad open folds; dips on the limbs of these folds are generally less than 35 degrees. In the vicinity of the Warden Station many of the folds are asymmetrical. Dips on the steep limb range from about 65° to 90° but no overturned beds were observed. The folds of the Love Station fold belt are typically 2 to 5 miles long and 1/4 to 1 mile wide. In Texas most of these folds plunge southeast at 15° to 20° and strike 20° to 30° northwest. In Mexico (Reaser, MS.), most of the folds of La Cuevita area plunge northwest.

The largest folds of the belt are an anticline and a syncline exposed in the Rincon north of Smugglers Gap. The anticline, which is 5 miles long and a mile and a half wide, has been breached; it forms the valley called "El Rincon." The syncline is composed of more resistant beds that form the east rim of the Rincon. The synclinal mountain and anticlinal valley form excellent examples of topographic inversion.

MINOR FOLDS

Superimposed on the limbs of the major and intermediate folds are small folds that locally make the geologic structure very confusing. These folds appear to be disharmonic; they die out vertically in a relatively short distance.

In transverse section the shape of the folds most commonly resembles that of the letter Z, but some of the folds are S-shaped, and in some localities the cross section resembles the Arabic numeral 2. The 2-shaped folds were given the field name "knee" folds because of the resemblance of the fold to a "bent human knee"; the horizontal limbs of the fold would be the thigh and foot, the vertical limb the shin, and the hinges the knee and instep.

The outcrop patterns of the folds are controlled by four factors: (1) the geometric form of the fold, (2) the attitude of the fold, (3) the orientation of the exposed section, and (4) the depth of erosion within the fold. The geometric form and attitude of the folds are fairly consistent; therefore, the outcrop pattern that developed is primarily controlled by the orientation of the exposed section and the depth of erosion within the fold. The most common geometric forms are Z-shaped folds whose longitudinal axes are parallel to the strike of the larger folds with which they are associated and whose axial surfaces are nearly horizontal. The resulting outcrop pattern is then controlled by the resistance of the rocks to erosion and the resulting topography. Reaser (MS.) and Jones (1968) have described these folds in more detail.

FAULTS

The faults in the area are grouped into two major sets. One set strikes northwest, the other northeast to east-northeast. Faults with a northwest trend include both thrust and normal faults. The faults with a northeast to east-northeast trend are the more numerous and include strike-slip and normal faults.

NORTHWEST-TRENDING FAULTS

Quitman thrust fault.—The Quitman thrust fault, named by Huffington (1943, p. 1024), can be traced from the Quitman Gap area southeastward for about 8 miles to Smugglers Gap. According to Albritton and Smith (1965, p. 105), the thrust can probably be traced north of the map area for another 5 miles.

The Quitman thrust breaks across the overturned limb of the Quitman anticline, thrusting it to the east-northeast. Along the fault trace, overturned beds of the Quitman, Cox, Finlay, and Benevides Formations in the upper plate are thrust over a normal sequence of beds of the Cox Formation and the upper and middle (reef) members of the Benevides Formation.

The thrust fault is well exposed at only one place where it dips about 30° west. This exposure is south of the Tammen ranch headquarters where the overturned upper member of the Quitman Formation has been thrust eastward over normal beds of the Cox Formation. Access to the fault exposure was restricted, but the thrust fault can be seen from the Quitman Gap road and has been described by Huffington (1943, p. 1024) and Albritton and Smith (1965, p. 106).

Throughout the remainder of the area the surface of the thrust fault is either poorly exposed or completely covered by alluvium and float. In a few places the fault surface can be located by the intense fracturing in the overthrust plate, but at most localities the break appears to be very sharp with only minor fracturing in the beds above and below the fault. The thrust surface is relatively easy to locate in those parts of the area where beds of different composition are in juxtaposition. Where beds of similar composition are juxtaposed by the fault, other criteria are necessary. Throughout much of the distance from Quitman Gap to Smugglers Gap, overturned beds of the Cox Formation have been thrust over a normal sequence of the Cox Formation. In these localities cross-bedding was used to determine attitude and the thrust placed between the uppermost (lowermost topographically) overturned sandstone and the uppermost normal sandstone. The fault trace could generally not be located more accurately than 50 to 100 feet, but at the scale of the geologic map the error is minor. In some localities, discordant strikes of the beds above and below the fault surface made it easier to map the fault trace on aerial photographs than in the field.

At the few localities where the attitude of the thrust fault could be measured or calculated with reasonable accuracy, the fault surface dips 20 to 30 degrees. Lower dips of the fault surface are present in the area but it is difficult to determine whether these dips have been affected by tilting of blocks between normal faults that occurred after the thrusting. The sinuous trace of the fault indicates that dips less than 30 degrees are general throughout the map area. A reconstruction of the thrust fault and the overturned anticline suggests a slip along the fault of about 5,000 feet, which agrees with the amount of slip suggested by Albritton and Smith (1965, p. 106).

At some localities the overthrust plate has been cut through by erosion or broken by normal faulting. Two large klippen are present on the east ridge of the mountains and smaller ones are present on the downthrown side of the West Mill fault on the east side of the mountains.

The Quitman thrust fault is offset only by normal faults and can be traced almost without interruption from Quitman Gap to the vicinity of Smugglers Gap. The fault can be traced about a quarter of a mile south of Smugglers Gap, but farther south its trace is covered by alluvium in the valley in the Benevides Formation. This valley is covered by alluvium throughout most of its length, and the presence or absence of the thrust fault must be determined by stratigraphic and structural interpretation rather than by direct observation. There is no compelling reason to extend the fault beyond the Smugglers Gap area. In fact, the extension of the thrust fault south of this area would complicate rather than simplify the structural interpretation.

Minor thrust faults.—Two small thrust faults were mapped west of the Quitman thrust in the vicinity of the Soto triangulation station. These faults are confined to the Quitman Formation and were mapped from aerial photographs entirely, an admittedly hazardous operation. The faults, however, are located on property to which access was denied.

Normal faults.—A large normal fault, downthrown to the southwest, bounds the southern Quitman Mountains on the southwest. Although this fault is concealed throughout most of the length of the mountains, evidence for its existence appears to be conclusive. The fault also extends southeastward into Mexico (Reaser, MS.), and, according to Huffington (1943), it continues northward along the southeast side of the northern Quitman Mountains. Jones (1968) proposed that the fault be called the "Caballo fault" and that name is used in this report.

Evidence for the existence of the Caballo fault along the west side of the Quitman Mountains is as follows:

1. The boundary between Cretaceous rocks and bolson fill is sharp at most places.
2. From Red Bull Spring south to Indian Hot Springs the strike of the beds is at an angle to the boundary between the Mountain Formation and bolson fill.
3. In localities where the Mountain Formation dips to the east there is a flattening or reversal of dip adjacent to its contact with the bolson fill. An example is shown on the map a short distance north of Red Bull Spring. At places where the Mountain Formation dips to the west, dips increase near the contact with the bolson or near where projection of the fault trace indicates it should be.
4. Fracturing in the Mountain Formation is more intense near the contact of the bolson fill.
5. The fault can be traced in bolson fill for about 2 miles north of the point where it crosses Caballo Arroyo. It offsets bolson fill in this area.
6. Hot or warm springs are present along the contact of the bolson fill and Cretaceous rocks at two localities, Red Bull Spring and Indian Hot Springs.

A large normal fault, downthrown to the northeast, bounds the Cajoncito area on the northeast side. This fault was designated the Schroeder fault by Jones (1968). Volcanic rock and the limestone beds of the Espy Formation are abruptly terminated or are in juxtaposition with bolson fill. A prospect pit in the fault zone yielded fragments of most of the Cretaceous formations in the area. Bell (1963, Pl. 1) extended the fault southward into Mexico. Its lateral extent to the north is unknown because the trace is covered by bolson fill. The Schroeder and Caballo faults bound a north-northwest-trending graben. At Cajoncito the graben is about 3.5 miles wide but it narrows in the vicinity of Hot Springs to 2 miles (Reaser, MS.).

The amount of displacement of these two faults can only be estimated from wells drilled in the area and measured thicknesses of bolson fill. Bell (1963, p. 58) measured more than 3,000 feet of bolson fill west of Indian Hot Springs. The deepest water well in the area is only 450 feet deep and it bottomed in fill. The displacements of the faults are probably on the order of 2,500 to 3,000 feet.

Smaller faults with displacement of from 100 to 500 feet are present within the southern Quitman Mountains. The strike of these faults is roughly parallel to the large boundary faults (N.30°W.), and they are probably genetically related to them. Most of these faults are in the northern half of the area mapped and are downthrown to the northeast.

NORTHEAST-TRENDING FAULTS

The Quitman Mountains are broken by a large number of faults that strike from N. 50° E. to N. 70° E. These faults are mostly dip faults and are easily recognized either in the field or on aerial photographs by the offset or abrupt termination of beds.

Although the strikes of these faults vary 20 degrees, the dips of all faults observed are more than 85 degrees. Most fault planes are not well enough exposed to permit direct measurements of their dips, but the fact that the fault traces are almost straight lines across all topographic features is considered as strong evidence that the fault planes are vertical or nearly so.

The direction of relative movement of these faults cannot generally be determined. For most faults, normal, strike-slip, or oblique movements could result in the same offset of beds.

Although there is no conclusive evidence as to the relative direction of movement of most of the faults, indirect evidence indicates that the movement is probably strike slip. The apparent relative movement includes both right and left lateral separation. Reaser (MS.) pointed out that some features of northeast-trending faults in the Cieneguilla area are considered by DeSitter (1959, pp. 173-174) to be characteristic of wrench faults. Some of these characteristics in the map area are:

1. Relatively straight fault trace.
2. Steep to near-vertical dip.
3. Faults show up distinctly on aerial photographs and in the field even though there may have been almost no movement along the fault surface.
4. The angle between the faults and the postulated principal stress direction is less than 45 degrees.
5. Faults are not en echelon but consist of numerous smaller faults parallel and similar to the larger faults.
6. The faults cut across the overturned folds as well as smaller folds; thus they belong to a later phase of deformation than the folding.

Red Bull fault zone.—The Quitman Mountains are broken into two segments along an east-northeast-trending fracture zone designated the Red Bull fault zone by Jones (1968). The amount of horizontal separation between the base of the Quitman Formation north and south of the fault zone is approximately 1 mile. The separation between the top of the Quitman Formation is only about a quarter of a mile. The difference in the amount of separation between the top and bottom of the unit is the result of repetition of the middle member of the formation by folding and faulting. That is, the Quitman Formation north of the fault zone has a wider outcrop than the same formation south of the zone. Reaser (MS.) has called attention to similar changes in outcrop widths in the Espy Formation adjacent to strike-slip faults in the Sierra Cieneguilla area.

The fracture zone consists of two major faults, which strike approximately N. 70° E. and have vertical dips, and numerous small faults. Most of the horizontal separation between beds occurs along the north fault of the zone. This fault splays into a series of branching faults along the eastern end of the zone. Rotation or separate movement occurred within the blocks separated by these branching faults. The straight traces of the north fault and its branches, their vertical dips, the outcrop patterns on either side of the faults, and the drag along them indicate that the predominant movement along the faults was strike slip. These faults are covered by volcanic rocks at their eastern end, indicating that they are older than the volcanic sequence. The north fault is well exposed on both sides of a narrow canyon cut by Mayfield Arroyo through massive limestone of the upper member of the Quitman Formation north of the Indian Hot Springs road.

The south fault of the fracture zone offsets both the Cretaceous strata and the volcanic rock sequence. The fact that this fault offsets the volcanic sequence indicates that either the fault is younger than the volcanic sequence or it has at least undergone renewed movement after the deposition of the volcanic sequence. The age and direction of movement of the fault are difficult to determine, but the separation of Cretaceous beds appears to be more than that of the volcanic rocks. Moreover, the apparent offset of a minor Z fold suggests that the first movements were mainly strike slip. Drag along the fault indicates that later movement was primarily vertical. Probably the fault developed as a left lateral strike-slip fault at the same time as the other faults in the zone. After the extrusion of the volcanic sequence further movement occurred along the fault but the later movement was primarily vertical. This fault is well exposed along the Indian Hot Springs road from Mayfield Arroyo west to the top of Quitman Summit.

Many ranges in the eastern part of the Chihuahua tectonic belt are composed mostly of intensely deformed carbonate rocks. DeFord (1964, p. 121) stated that the complicated folding of Cretaceous limestone in the mountains of this belt suggested the presence of underlying salt or anhydrite. No evaporites are exposed in the southern Quitmans but are known to crop out in the Malone Mountains to the north and in Cañón de los Frailes to the west in northern Chihuahua (Haenggi, 1966, p. 145). The Jura-type folds exposed in the southern Quitmans and adjacent ranges in Mexico are probably related to a décollement.

GEOLOGIC HISTORY

Cretaceous Period.—The depositional history of the rocks exposed in the area mapped began during early Cretaceous (Neocomian?) time and sedimentation appears to have been essentially continuous until at least early Late Cretaceous (Turonian) time. Vertical changes in composition are interpreted to be a reflection of a shifting shoreline during the general northward and eastward transgression of the Mexican sea onto the Diablo Platform. The transgression resulted in the onlap of Upper Jurassic and Lower Cretaceous formations and in overstep of eroded Paleozoic and Precambrian rock in areas adjacent to the Quitman Mountains.

The oldest rock exposed in the area is the lower member of the Mountain Formation (Neocomian?) tentatively correlative with the Navarette Formation of Haenggi in El Cuervo area. Haenggi (1966, p. 36) suggested that the carbonate and the siliciclastic beds of the Navarette Formation are interbedded with gypsum and may grade laterally into gypsum.

Pulmonate gastropods, vertebrate remains, and charophyte remains, in addition to the fine-grained carbonate and siliciclastic strata, indicate that the rocks of the lower member of the Mountain Formation were deposited in bay and lacustrine environments. Probably they were deposited in bays or lagoons along the margin of the Mexican sea. It is possible that such deposits could grade laterally into evaporites if an evaporite basin did, in fact, exist during early Cretaceous time.

During late Neocomian or early Aptian time relative uplift of the Diablo and Coahuila Platforms and subsidence of the Chihuahua Trough resulted in a tremendous influx of clastic detritus into the area. The rocks of the middle member of the Mountain Formation record the cyclic deposition of sediments of an alluvial plain complex (Campbell, 1968).

As erosion reduced the elevation of the Diablo Platform, lacustrine and bay environments were again established in the area. Fine-grained carbonate and fine-grained siliciclastic strata of the upper member of the Mountain Formation accumulated in association with charophyte remains, gastropods, bone fragments of vertebrates, and fossil wood.

Rocks of the Quitman Formation record the transition from an environment of vigorous wave action to one of quiet water. Thick-shelled pelecypods, calcareous sandstone, abundant shell fragments, and oolites in the lower member of the formation attest to vigorous wave action. The change up section from sandstone, sandy limestone, and fossiliferous, coarse-grained limestone of the lower member to the calcareous shale, siltstone, and limestone of the middle member reflects a gradual decrease in wave and current action as the sea transgressed onto the platform to the east. Continued transgression resulted in a widespread shallow-marine environment that included a complex of reefs and carbonate banks. It resulted in the deposition of the fine-grained reef limestone of the upper member as well as thin- to thick-bedded limestone which contains *Orbitolina* sp. at many localities.

The general eastward advance of the Mexican sea onto the Diablo Platform was interrupted many times during late Early Albian and early Middle Albian stages. The alternating transgressions and regressions are recorded in the shallow-water marine deposits of the Cox Formation.

During Middle Albian time the Mexican sea again began transgressing and by the end of Middle Albian time had inundated most of the Diablo Platform. Carbonate rock of the Finlay, Espy, and Buda Formations was deposited in a broad shallow shelf during the transgressive stages. Relief on the carbonate shelf was so low that slight changes in sea level affected large areas of the depositional province. This general transgression was interrupted briefly during late Albian and early Cenomanian time. The regressions are recorded in terrigenous rock of the Benevides and Eagle Mountains Formations.

A 2,000-foot sequence of terrigenous material with minor carbonate rock was deposited in the area during the Gulf Epoch. A study of these rocks indicates that beds of the Ojinaga Formation recorded the continued transgression of the Mexican sea during the Cenomanian and early Turonian stages.

Laramide orogeny.—During late Cretaceous to early Tertiary time the sedimentary rock in the Chihuahua Trough was intensely deformed. The youngest rocks, now exposed, that were involved in the deformation compose the Ojinaga Formation (Turonian). Relatively undeformed volcanic rock overlies truncated Cretaceous rock. Therefore, the culmination of the intense deformation was later than the youngest Cretaceous rock (Turonian) and earlier than the oldest volcanic rock (Oligocene?) in the southern Quitman Mountains. The widespread late Cretaceous to early Tertiary deformation in the western part of North America has been called the Laramide orogeny.

Cenozoic Era.—Although the early Cenozoic Era was a time of intense deformation, presumably erosion was sufficient to prevent the development of extreme differences in elevation. The drainage system that developed on the rising fold probably produced a ridge and valley topography much like that of the present-day Quitman Mountains. The existence of this drainage is indicated by the presence of a conglomerate at the base of the volcanic sequence in Calvert Canyon. The conglomerate overlies truncated Cretaceous strata and contains clasts from most of the Cretaceous formations.

Widespread volcanic activity during early Tertiary time spread a blanket of extrusive rock over large areas of Trans-Pecos Texas and northern Mexico.

Scattered outcrops of volcanic rock in the Quitman

Mountains, Cajoncito area, and Red Light Bolson indicate that much, if not all, of the area was covered by volcanic rocks at one time. Erosion has removed these extrusive rocks except in areas where they were probably thickest. Present data suggest that the volcanic sequence in the southeast part of the area filled a valley cut into Cretaceous rocks.

During mid-Tertiary time, northern Chihuahua and western Trans-Pecos Texas were uplifted several thousand feet and block-faulted (DeFord and Bridges, 1959, pp. 292, 293). In the southern Quitman Mountains this faulting occurred after vulcanism; it produced the Hueco Bolson and was at least partly responsible for the development of the Red Light Bolson. The block faulting disrupted the existing drainage system and replaced it with closed intermontane basins. Material eroded from the highland areas was deposited in the basins as a series of coalescing alluvial fans.

As erosion of the highland areas continued, the intermontane basins began to fill. In essence the mountains or highland areas were being "drowned" in their own debris. That the southern tip of the Quitman Mountains was entirely covered by debris is indicated by stream gravel on ridges several hundred feet above the Rio Grande. This gravel and the bolson fill in the Quitman Gap area indicate that the highlands were covered to a level above 4,000 feet. Strain (1966, p. 11) suggested that the Hueco Bolson aggraded to a level of approximately 4,200 feet. The Cajoncito area was covered by bolson fill as was the extension of the Quitman range in Mexico (Reaser, MS.).

During Pleistocene time the Rio Grande breached the Hueco and Red Light Bolsons. Once the basins were breached, erosion of the bolson fill began and a new drainage system, tributary to the Rio Grande, developed. Erosion by the Rio Grande and its tributaries has removed several hundred feet of bolson fill. Probably the Rio Grande was superimposed on the buried southern Quitman Mountains and on the Cretaceous rocks of the Cajoncito area. The Rio Grande has begun to adjust its course to the structure of the bedrock in these two areas. Many of the smaller stream courses in the mountains are clearly controlled by the lithic character and the structure of the bedrock and should be classed as subsequent streams.

The rate of downcutting by the Rio Grande and its tributaries has not been constant but has varied with such factors as climate, composition of rocks, and, perhaps, tectonic activity. The result of these variations was the development of at least three pediments. It is generally agreed that the pediment surfaces are the result of lateral planation of tributary streams during stillstands of the Rio Grande. It is also generally agreed that alternate downcutting and stillstands of streams in western Trans-Pecos Texas are related to alternation of arid and "wet" (less arid) climates during the Pleistocene Epoch. Underwood (1962, p. 358) concluded that downcutting occurred during the arid cycles, but there is not general agreement on this point.

ECONOMIC GEOLOGY

WATER

The economy of Hudspeth County, as well as most of western Trans-Pecos Texas, is based on farming and ranching. Because the average rainfall in the area is less than 10 inches per year (Reaser, MS.), water or the lack of water is of vital concern to the inhabitants of the area.

Potable water can be obtained at most places from gravel in bolson fill at a depth of 100 to 600 feet. Wells produce sufficient water for livestock and for household purposes. Wells on the Armstrong ranch in the Red Light Bolson provided water for building Interstate Highway 10 between Sierra Blanca and Van Horn. The water was pumped about 20 miles from the ranch over Devil Ridge to the construction site. Although the water had to be pumped, the Red Light Bolson was the closest and cheapest source of water of good quality in the area.

Wells drilled in the Hueco Bolson produce excellent water at about 200 to 300 feet. No attempt has been made to pump large volumes of water from these wells, but wells drilled near the Quitman Mountains or the Cajoncito area might produce sufficient water for large-scale irrigation. Wells in the Rio Grande Valley generally produce large volumes of water from river gravel, but the high sodium chloride content prohibits extended use of the water for irrigation.

Periodic runoff in the Rio Grande is used to irrigate two farms on the flood-plain of the river in the area mapped where the runoff in the Rio Grande is dependent almost entirely on rainfall within Hudspeth County or adjacent areas in Chihuahua, Mexico. The runoff is irregular and cannot be depended upon as a source of irrigation water.

SPRINGS

Red Bull Spring.—Water flows to the surface of the Red Bull Arroyo at the junction of the bolson fill and the Mountain Formation. This locality is also the intersection of the Red Bull fault zone with the Caballo fault. As the water is warm and has a high mineral content, its origin may be related to that of the Indian Hot Springs about 2 miles south. Before the Valentine earthquake in 1931, the discharge of Red Bull Spring was sufficient to make Red Bull Arroyo a perennial stream (Ike Kelcy, personal communication, 1964). At the present time, the water flows only about a mile below the spring before it is absorbed by alluvium.

Indian Hot Springs.—Local legend, as well as abundant artifacts, suggests that a group of springs at the south end of the area were used by Indians (probably Apaches) before the area was settled by white men. Because the water of most springs in the area is warm and not potable, the springs were probably used for medicinal and therapeutic purposes. Since the time of the Indians, many other people have followed their practice. A resort hotel, guest houses, and bath houses were built at the springs during the late 1920's (John Bramblett, personal communication, 1964). The resort operated with varying success until it was finally closed in about 1962. After the field work for this report was completed, the hotel and two sections of land surrounding it were purchased by new owners and the buildings and grounds have been completely renovated. The resort was reopened in 1967.

Bell (1963, pp. 65-66) suggested that most of the springs are actually shallow artesian wells dug into the flood-plain of the Rio Grande. The water appears to rise along the Caballo fault east of the springs and flows through bolson fill, discharging into the wells and topographically low areas. Most of the springs now in use were probably dug when the Indian Hot Springs resort was built in the late 1920's. Although 6 to 10 springs have been reported by local ranchers only 4 springs were flowing in 1969. Mrs. Jewell Babb (personal communication, 1964) stated that several springs were buried by stream deposits of the Rio Grande during a major flood in 1962.

METALLIC MINERALS

No deposits of metallic minerals were observed in the area. A prospect pit on the Bramblett ranch was dug into a mineralized fracture zone in the Finlay Limestone. An examination of the fracture zone and of the dump indicated that hematite and limonite were the only metallic minerals present.

NONMETALLIC MINERALS

Sand and gravel and building stone are abundant in the area. These deposits have little commercial value except locally, because of the cost in transporting them to potential users. Limestone from the upper member of the Quitman Formation was quarried north of the Neely ranch house and used as fill and riprap in the construction of levees along the Rio Grande. Locally, sand and gravel and caliche are quarried for maintaining and repairing county and ranch roads.

PETROLEUM

The prospect of finding petroleum in Cretaceous strata appears to be poor. Although many structural traps are exposed in the Quitman Mountains and more traps are probably present beneath the deposits of the Red Light Bolson, erosion appears to have exposed most potential reservoir rocks, thus greatly reducing the prospects of finding petroleum. The Red Light Bolson offers a better possibility of containing petroleum accumulations than the remainder of the area.

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