Geology of the Sierra Blanca Area Hudspeth County Texas

GEOLOGICAL SURVEY PROFESSIONAL PAPER 479

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By CLAUDE C. ALBRITTON, Jr., *and* J. FRED SMITH, Jr.

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Geologic history of a border between a rigid structural platform and a mobile geosynclinal belt

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By Claude C. Albritton, Jr., and J. Fred Smith, Jr.

ABSTRACT

The Sierra Blanca area covers about 950 square miles in Hudspeth County, Tex., along the Mexican border and includes the Triple Hill, Finlay Mountains, and Sierra Blanca 15-minute quadrangles and the parts of the Fort Quitman and McNary quadrangles within the United States.

The area lies athwart the border between the Basin and Range province on the north and the Sierra Madre Oriental province on the south. In the report area the two provinces have maintained their identities for a long span of time that probably extended back into the Precambrian. The northern province generally behaved as a rigid platform, whereas the southern province was much more mobile. This difference in behavior is reflected in the depositional history.

The rock record in the area of this survey began during the Early Permian (Leonard) when the mobile area may have been the site of part of a basin and the platform was the northeastern shelf of that basin. Then, after a period of uplift and erosion, the mobile area sank to form the northern part of the Mexican geosyncline in which Late Jurassic and Cretaceous sediments were deposited. A more widespread regional subsidence after the Neocomian Stage of the Cretaceous permitted the Mexican sea to spread beyond the confines of the geosyncline and onto the edge of the platform, but throughout Early Cretaceous time the greatest subsidence was in the mobile belt. The sea alternately advanced and retreated over the platform during part of Early and Late Cretaceous times until the region was deformed, uplifted, and eroded before it received volcanic rocks of Tertiary age.

Rocks of the Leonard Series of the Permian System consist of 1,650 feet of marlstone, limestone, and conglomerate in the Finlay Mountains along the south edge of the northern province; they contain both marine fossils and leaves and fronds of terrestrial plants and were probably deposited near shore. Rocks that may also be largely of Leonard age consist of interbedded gypsum, limestone, and dolomite in the Briggs Formation in the Malone Mountains of the southern province. As the two sequences not only are disconnected but also are separated by a major thrust fault, their relationship is obscure.

Rocks of the Jurassic System occur only in the southern province, where they are represented by the Malone Formation, made up largely of clastic materials. The formation is about 1,000 feet thick but is thinner locally on account of irregularities of the surface on which it was deposited. Although of marine origin, it contains driftwood and evidently was deposited near shore. Ammonites indicate that the formation corresponds approximately to the Kimmeridgian and Tithonian Stages.

The oldest rocks of the Lower Cretaceous Series, largely of Neocomian age, are also restricted to the southern province, where they are divided into the Torcer Formation, Etholen Conglomerate, and Yucca Formation. The Torcer is composed of about 400 feet of clastic limestone and basal quartzite and conglomerate and lies conformably on the Malone Formation. The Etholen is coarse conglomerate and breccia, at least 700 feet thick, and crops out only near the border of the two structural provinces; it may be equivalent in part to the Torcer Formation. The Yucca is a heterogeneous mixture made up chiefly of clastic rocks and in the southern part of the area is more than 5,500 feet thick. All three formations are sparsely fossiliferous.

The remainder of the Lower Cretaceous Series forms a sedimentary wedge that thins from 4,500 feet in the southern province to 2,500 feet in the northern. The rocks in the south are chiefly marine limestone, but those in the north include thick units and tongues of sandstone. This part of the series is divided into the Bluff Mesa Limestone, whose partial equivalent in the north is the Campagrande Formation, and the Cox Sandstone, the Finlay Limestone, the Kiamichi Formation, and rocks of Washita age (undivided).

The Bluff Mesa Limestone is 1,080 to 1,475 feet thick and consists largely of limestone containing abundant marine fossils. The large foraminifers *Orbitolina texana* (Roemer) and *O. minuta* Douglass are confined to this formation and form whole layers of rock at certain horizons. Thinner near-shore equivalents of this formation in the northern province compose the Campagrande Formation, the lower part of which is made up of siltstone and other clastic rocks and is possibly nonmarine; the upper part is largely marine limestone.

The succeeding Cox Sandstone is about 1,300 feet thick in the southern province, where it includes much marine limestone. To the north it is about 500 feet thick, consists largely of sandstone, siltstone, and shale, and contains abundant petrified driftwood in some beds.

The Finlay Limestone, the most nearly homogeneous of the Cretaceous formations, thins from 510 feet in thickness in the south to less than 200 feet in the north; it is mostly limestone but contains sandstone lenses in the northern part of the area. Its numerous marine fossils include the foraminifer *Dictyoconus walnutensis* (Carsey).

The Kiamichi Formation consists of interbedded shale, sandstone, limestone, and marl in the southern province, where it is 235 feet thick; to the north it is dominantly sandstone and is probably no more than 200 feet thick. It contains ammonites and other marine invertebrates.

Rocks of Washita age are about 1,000 feet thick. They consist chiefly of interbedded marl, limestone, and shale, and contain diversified marine invertebrates.

Arkosic sandstone and siltstone of the Upper Cretaceous Series undifferentiated are more than 675 feet thick and lie conformably on rocks of Washita age at one locality near the boundary between the two provinces. Fossils suggest that the beds are of Eagle Ford age. In the report area these are the youngest exposed rocks that are older than the major deformation of the region.

During the Laramide deformation in latest Cretaceous or early Tertiary time, the Cretaceous and older rocks in the mobile southern province were folded and thrust several miles northward against the adjoining platform. They were broken into three blocks bounded by thrust faults that trend northwestward and dip southwestward. Strata of the northernmost or Devil Ridge block are homoclinal and dip southwestward. Strata of the medial or Red Hills block are intricately folded.

Strata of the southernmost or Quitman block are mostly on the northeast limb of a single large anticline overturned toward the northeast. Traces of the three principal thrusts converge northwestward and may become a single fault in the western part of the area. In the northern province the thinner sequence of strata was warped into broad open folds that were fractured locally by small normal faults.

After an interval of subaerial erosion, rhyolite, trachyte, and other lavas were erupted near the margin of the two provinces to form the Square Peak Volcanics, which are about 3,500 feet thick in the northern part of the Quitman Mountains. The volcanic rocks and the adjacent sedimentary rocks were subsequently intruded by the monzonitic Quitman pluton, which has an elliptical outcrop suggestive of a ring dike; the volcanic rocks subsided inside the ring, and this ovate structure might be interpreted as an ancient small caldera. Rhyolite laccoliths and andesite porphyry and latite porphyry sills were injected into the less deformed strata of the northern province, and a few dikes were intruded into rocks of both provinces, presumably at about the same time as the emplacement of the Quitman pluton. None of the igneous rocks are accurately dated; on scanty evidence from outside the report area, the volcanic rocks may be of Eocene or Oligocene age and the intrusive rocks, only slightly younger.

In late Tertiary time, highlands and lowlands were formed in parts of the southern province and tne transitional belt north of it. The Hueco Bolson, largest of the lowlands, was a basin of internal drainage during the Pliocene, when it was filled by many hundred feet of sand, clay, and gypsum, which grade into fanglomerate near the mountains.

External drainage through the Rio Grande Valley probably was established early in Pleistocene time. Ancient channel deposits with gravels from distant sources were entrenched in older alluvium of the Hueco Bolson. After incision of the initial channel of the Rio Grande, the river shifted and lowered its course to its present position in the El Paso Valley. Five gravel-capped surfaces and two cut-and-fill terraces mark successive stages in this process, during which traces of the original valley were destroyed by planation. Other surficial deposits include alluvium, colluvium, and windblown sand.

Principal natural resources of the Sierra Blanca area are ground water, clay, gypsum, gravel, and building stone. Metalliferous deposits near the igneous rocks of the Quitman Mountains have been extensively prospected, but results have been disappointing. Up to 1960, search for oil and gas had been unsuccessful, although the southern province with its thick sedimentary sequence and intricate structure had not been adequately tested.

INTRODUCTION

AN ANCIENT STRUCTURAL BOUNDARY

In this report we reconstruct the history of an ancient boundary between a rigid structural platform and a mobile geosynclinal belt. The platform is now part of the Basin and Range province, and the mobile belt is part of the Sierra Madre Oriental. Within the limits of four 15-minute quadrangles centering near the town of Sierra Blanca, Tex. (fig. 1), these two provinces have maintained their separate identities since Late Jurassic time and probably since Permian time. Studies of adjoining areas by other geologists suggest that the mobile belt and the stable platform were in existence even in Precambrian time.

The boundary between the Sierra Madre Oriental and the Basin and Range province is more sharply defined in the report area than elsewhere. From the gap between Sierra Blanca Peak and the Quitman Mountains, the boundary extends eastward near U.S. Highway 80 toward Van Horn east of the mapped area (fig. 1). Westward, the boundary crosses the Hueco Bolson between Campo Grande Mountain and the Finlay Mountains.

Landscapes north and south of the boundary have arresting contrasts. The Diablo Plateau on the north is a broad tableland carved by erosion into scattered mesas and cuestas. To the south is a corrugated terrain of ridges and sierras alternating with broad bolsons.

Differences in surface configuration reflect differences in composition and structure of the underlying rocks. In most of the Diablo Plateau, strata of Mesozoic and older ages are nearly horizontal, but along the Sierra Madre front they are folded. Rocks of both regions are faulted, but the faults are more closely spaced in the Sierra Madre, and many of them are thrust faults.

The stratigraphic relations indicate that the region to the south subsided repeatedly relative to the adjacent platform and has thus been a catchment area for a disproportionately thick accumulation of sediments. This region forms the north end of the Mexican geosyncline. Sedimentation began in this geosyncline during Late Jurassic time but did not extend into the area of the adjacent platform on the north until after earliest Cretaceous time. Striking differences between the facies of the Permian rocks of the two regions are probably also related to positive movements of the Diablo platform.

A few miles east of the Sierra Blanca area, the boundary between the two provinces separates unlike sedimentary facies within the Precambrian rocks, the thicker, finer grained, and more strongly deformed sequence again being on the south side. Several geologists have interpreted this structural boundary as an ancient belt of fracture that extends far beyond the Sierra Blanca area across part or all of the North American continent and have termed it the "Texas lineament." If such a hypothetical fracture belt exists, it is one of the longest structural lines in the world.

We leave it for others to decide whether the boundary described in this report was ultimately controlled by deep-seated fractures of local, regional, or continental proportions. Our concern here is with the boundary's dimension in time, which is set forth in a systematic account of the local rock units, their structural relations, and their expression in the present landscape. The geological chronicle begins with the Permian and ends with the present.

THE SIERRA BLANCA AREA

LOCATION AND CULTURE

The Sierra Blanca area covers about 950 square miles in southern Hudspeth County, Tex. It includes the Finlay Mountains, Triple Hill, and Sierra Blanca 15-minute quadrangles and the parts of the Fort Quitman and McNary quadrangles that are in the United States northeast of the Rio Grande (fig. 1).

Sierra Blanca is the county seat of Hudspeth County and is the principal town. Two railroads, the Southern Pacific and the Texas and Pacific, join here from the east and use the same line northwestward to El Paso. U.S. Highway 80, a main east-west route across Texas, crosses the southern half of the area. Much of the country away from the highway is accessible from county and ranch roads. A county road parallel to the Rio Grande serves farms and ranches near the river; a road to Carlsbad, N. Mex., leads northward from Sierra Blanca across the Diablo Plateau to U.S. Highways 62 and 180; a third county road extends southward from Sierra Blanca down Quitman Canyon to the Rio Grande. A road through Quitman Gap connects the road down Quitman Canyon with the one along the Rio Grande. Quitman Gap was one of the more difficult stretches along the old stage route leading westward to Fort Quitman and El Paso.

Principal economic activities of the region are stockraising and farming. Farming is confined to irrigated parts of the Rio Grande flood plain.

PHYSICAL FEATURES

The area is divisible into the seven topographic parts shown on figure 1.

The Diablo Plateau is a tableland of low relief, mostly between 4,400 and 5,200 feet in altitude. The surface is formed of mesas and cuestas that rise 100 to 200 feet above broad valleys; most of the hills and valleys are elongated eastward. The south edge of the plateau extends as a scalloped escarpment across the northern half of the area. West of the Finlay Mountains, its rim projects abruptly in cliffy slopes 450 feet above the Hueco Bolson, but farther east the height decreases and the escarpment is discontinuous. All streams of the plateau are ephemeral, and most drain northward or eastward from a divide near the southern edge of the plateau.

The Finlay Mountains are elliptical in plan, elongated northwestward, about 10 miles long and 5 miles wide. Their core of flat-topped mountains, including Finlay Mountain (alt 5,704 ft), is encircled by a ring of hogbacks and cuestas. Northward, they connect with the Diablo Plateau. Ephemeral streams drain radially toward the west, south, and east into the Hueco Bolson, the border of which is about 1,400 feet below the higher parts of the mountains.

The Sierra Blanca peaks form a compact group of five subconical mountains just beyond the south escarpment of the Diablo Plateau. Sierra Blanca, a commanding landmark and highest mountain in the report area, rises 2,000 feet from surrounding flats to an altitude of 6,894 feet. Little Blanca Mountain, Round Top, Little Round Top, and Triple Hill are lower prominences. A cuesta extends several miles southeastward from Triple Hill, and smaller parallel ridges flank Sierra Blanca Peak on the south and southeast. An inconspicuous divide near the peaks separates arroyos draining eastward into an enclosed basin from those draining westward into the Hueco Bolson and the Rio Grande.

The Quitman Mountains-Devil Ridge area consists principally of two mountainous belts in the form of an acute V, pointing northwestward. The Quitman Mountains form the broader arm; the Malone Mountains are at the apex. A discontinuous line of hills and ridges—Etholen Hill, Bluff Mesa, and Devil Ridge—forms the narrower arm. The so-called Quitman Canyon is actually a broad intermontane valley separating the two mountainous belts. The Quitman Mountains rise 2,500 feet above the Hueco Bolson on the west and 2,000 feet above the lowlands on the east. North of Quitman Gap the mountains consist of a single massive ridge which is divided into four principal segments by canyons draining to the east and west. Each segment culminates in a pinnacled crest trending west to northwest. South of the pass, the mountains consist of several ridges parallel to the trend of the range. This condition is true also of the Malone Mountains and Devil Ridge. The Quitman Mountains-Devil Ridge area drains mostly to the Rio Grande down Quitman Canyon or along arroyos across the Hueco Bolson. Drainage through Quitman Gap apparently has captured part of the headwater area of Quitman Canyon.

Eagle Flat is a smooth alluvial valley, 25 miles long and 5 miles wide and separates the Diablo Plateau from mountains on the south. It is elongated northwestward and ranges in altitude from 4,300 to 4,500 feet. At its west end, near the town of Sierra Blanca,

FIGURE 1.—The Sierra Blanca area, the boundary between the Basin and Range province and the Sierra Madre Oriental, and the topographic subdivisions of the Sierra Blanca area including (1) Diablo Plateau, (2) Finlay Mountains, (3) Sierra Blanca peaks, (4) Quitman Mountains-Devil Ridge area, (5) Eagle Flat, (6) Hueco Bolson, and (7) El Paso Valley.

this lowland curves northward and merges with broad valleys that breach the south front of the Diablo Plateau. Drainage is largely internal and converges from the bordering plateaus and mountains into an ephemeral lake about a mile east of the border of the Sierra Blanca area. Part of the former drainage basin of the area northeast of Devil Ridge has been captured by branches from Quitman Canyon which lies to the southwest.

Only the southeast end of the Hueco Bolson extends into the Sierra Blanca area. Farther westward toward El Paso the bolson is a sandy plain, but in the mapped area it is intricately dissected by ephemeral tributaries of the Rio Grande. Flattish divides between arroyos slope toward the master stream across a series of descending erosional benches. Altitudes range from 3,500 to 4,500 feet.

El Paso Valley is the 90-mile-long segment of the Rio Grande flood plain between the narrows in the river at El Paso and the narrows below Fort Quitman. The valley floor in the Sierra Blanca area is at altitudes between 3,430 and 3,520 feet. It is a silty plain bordered by bluffs and low terraces. In the past the Rio Grande meandered widely over this plain, as indicated by numerous cutoffs and sloughs, but it is now largely channeled between artificial levees that both protect the croplands and stabilize the boundary between Mexico and the United States. The river is often dry or reduced to a trickle when water is being diverted into ditches for irrigation.

CLIMATE AND VEGETATION

The Sierra Blanca area is near the margin of a broad desert that extends far southward into the central plateau of Mexico. No regular records of the weather have been kept for many years, but data recorded at Sierra Blanca from 1891 to 1897 are summarized by the U.S. Weather Bureau in table 1.

Most of the rain falls as local thundershowers during the months of July and August, and the months from January through April are notably dry. Daytime temperatures during the summer months are commonly more than 100° F, but the nights are generally cool. Temperatures seem to differ considerably from one part of the area to another, largely because of the breezes in the higher parts; the air usually seems hotter in the Hueco Bolson, particularly near the Rio Grande, than in the bordering hills and mountains.

The ground is sparsely covered with grass, cactus, and scrub. Grasses grow in scattered patches on alluvial slopes and in places along the higher parts of the Quitman Mountains, but the only extensive grasslands are in the broad valleys of the Diablo Plateau. The pincushion cactus, barrel cactus, and pricklypear flourish in all parts of the area, and the fishhook cactus grows on rocky surfaces. Stands of ocotillo cover many of the rocky alluvial slopes. Other common plants of this semiarid country are yucca, century plant, lechuguilla, sage, and greasewood. Mesquite and willow find the water necessary for their survival along the larger arroyos and around cattle tanks. Small juniper trees are scattered widely over the hills and mountains, and the larger ones grow along the canyons.

FIELDWORK

Fieldwork on which this report is based was done in the summers of 1947, 1948, 1949, and 1951, and amounted to about 10½ months. We were capably assisted in 1947 by Earl B. Austin, Thomas E. Mullens, and William W. Webber; in 1948 by John D. Boon, Jr., Richard E. Byrd, Mark A. Clement, and Thomas E. Mullens; and in 1949 by Peter N. Wiggins III.

Geologic mapping (pl. 1) of the Finlay Mountains, Fort Quitman, Triple Hill, and McNary quadrangles was done on topographic base maps enlarged to a scale of 1:31,250 and with the use of aerial photographs. As an adequate topographic base was not available for the Sierra Blanca quadrangle, the base map and geologic map were compiled from aerial photographs by radial-line plotting, controlled by a triangulation net expanded from a measured base line by planetable and alidade. Most of the stratigraphic sections were measured trigonometrically by using a tape and a Brunton compass to measure the dips of strata and slopes of the surface. In some areas of almost horizontal beds, direct measurements of thickness were made with hand level or tape.

ACKNOWLEDGMENTS

Many helpful suggestions on interpretation of the geology were given by Philip B. King, who visited

TABLE 1.—*Precipitation, in inches, and temperature, in degrees Fahrenheit, at Sierra Blanca*

[Data summarized by U.S. Weather Bur.]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1891–98													
Average precipitation	0.13	0.26	0.19	Trace	0.64	0.66	2.34	2.17	1.32	1.10	0.31	0.33	9.45
1891–97													
Average temperature	48.6	49.0	54.8	64.2	71.1	78.2	79.4	77.3	72.9	63.4	56.5	48.0	63.6
Highest temperature	74	78	83	91	102	104	101	100	95	84	88	88	104
Lowest temperature	9	7	18	23	36	42	50	50	40	28	7	13	7

our party during the field seasons of 1948 and 1949. Prof. J. D. Boon, Jr., of Arlington State College, Tex., generously permitted us to use his unpublished geologic map of the Sierra Blanca peaks and vicinity. Our thanks are extended to them and to Roy M. Huffington, who shared with us his extensive knowledge of the northern part of the Quitman Mountains.

Residents of the Sierra Blanca area contributed much toward making our sojourns pleasant. All private roads were made accessible to us, and on several occasions the ranchers and townsfolk guided our party to geologic features.

PREVIOUS INVESTIGATIONS

Little was known of the geography and geology of the Sierra Blanca area until late in the 19th century. In 1849, Capt. S. G. French supervised construction of a road connecting San Antonio and El Paso through Quitman Gap. From the field notes of this and other military expeditions, maps were drawn to show landmarks along routes of travel through the Trans-Pecos region (French, 1850). In 1853 and 1854, C. C. Parry, M.D., studied the botany and geology along the Rio Grande as part of the work of the United States and Mexican Boundary Survey. He described the alluvial deposits of the intermontane basins and recognized that much of the alluvium came from the bordering uplands (Parry, 1857, p. 6, 49–50).

The first geologist to study the Sierra Blanca area was W. H. R. von Streeruwitz, who started work there for the Geological Survey of Texas in 1888. Streeruwitz's observations are recorded in great detail in the annual reports to the Director of the Survey for the years 1889 to 1893. He was an accomplished surveyor; his base map of the country along the Texas and Pacific Railway accurately shows the topography as well as the dip and strike of the stratified rocks. Sections accompanying the map show many of the broader structural features but very few of the faults. Streeruwitz also examined the mines and prospects of the Quitman Mountains and their ores of silver, copper, lead, and zinc. He noted that some of these contained uranium.

In 1890, J. A. Taff assisted Streeruwitz and studied the Cretaceous rocks; he (1891) drew up the first columnar section of the Sierra Blanca area. As Taff was unaware of the thrust faulting and other structural complexities, his sequence was largely inverted; but his descriptions of the strata are accurate, and several of his formation names are still in use.

Rocks and fossils collected by Streeruwitz were studied by various specialists. In a petrographic report, C. A. Osann (1893) identified the fine-textured rock of the Sierra Blanca peaks as igneous, rather than sedimentary as the collectors considered it. He also recognized that extrusive as well as intrusive rocks occur in the Quitman Mountains.

Fossils were identified by F. W. Cragin (1893). Those from the Malone Hills, the low hills east of Torcer, aroused his curiosity, as they appeared to be older than the Cretaceous; after obtaining additional specimens he (1897) concluded that they were of Jurassic age, and he later systematically described the Malone fauna (Cragin, 1905). His results gave rise to a long controversy, details of which are given in the section on Jurassic rocks (p. 35–37).

While Cragin was collecting fossils, Timothy W. Stanton measured stratigraphic sections in the Malone and Quitman Mountains. Near Quitman Gap and again near the south end of the Quitman range, Stanton established from fossils that the strata were overturned. His observations, published in Cragin's bulletin (1905), did much to clarify the stratigraphy and also made possible more detailed interpretations of the structure.

The first comprehensive geologic reports with geologic maps came from reconnaissance by George B. Richardson (1904) and Charles L. Baker (1927). Richardson described the area north of the Texas and Pacific Railway, Baker the area to the south. Essential features of Cretaceous stratigraphy of the Diablo Plateau were established by Richardson. Baker's discovery of thrust faults in the Quitman Mountains and in Devil Ridge indicated a greater structural complexity than anyone had suggested before.

Detailed studies of individual mountain groups began in 1934 with investigations of the Malone Mountains by Albritton (1937a and b, 1938) and were continued in Devil Ridge by Smith (1940), in the Finlay Mountains by Albritton and Ham (1941), in the northern Quitman Mountains by Huffington (1943), and in the Sierra Blanca Peak area by Boon (King, 1949).

ROCK FORMATIONS

Sedimentary rocks exposed in the Sierra Blanca area are of Permian to Recent age. The stratigraphy of the pre-Tertiary rocks is summarized in table 2. Unless otherwise indicated, all fossil identifications in this report are by Claude C. Albritton, Jr.

Deposits of probable late Tertiary and early Quaternary ages underlie the Hueco Bolson but are concealed over broad areas by more recent accumulations of alluvium, colluvium, and windblown sand. Igneous rocks of Tertiary age form the Sierra Blanca peaks and the greater part of the northern Quitman Mountains. Dikes and sills are present throughout the

TABLE 2.—*Summary of pre-Tertiary formations*

System	Series	Age	Formation	Lithology	Thickness (feet)	Where exposed
Cretaceous	Upper			Gray and brown fine-grained and very fine grained sandstone and less siltstone and shaly siltstone; much of the sandstone is arkosic.	[1] 675+	Etholen Knobs.
	Lower	Washita	Undivided	Massive gray limestone and nodular limestone and less marl, shale, and sandstone.	[2] 1,020±-1,400	Around Sierra Blanca peaks, east of north end Quitman Mountains, northeast of Devil Ridge, southern Quitman Mountains.
		— -?-?-?- —	Kiamichi	Gray shale, gray nodular limestone, and marl in southern Quitman Mountains; sandstone and some marl at north end Flat Mesa; sandstone on Diablo Plateau.	150±-235	Northeast corner of mapped area, north of Round Top, north end Flat Mesa, southern Quitman Mountains. Complete section exposed only in southern Quitman Mountains.
		Fredericksburg	Finlay	Principally gray limestone, some slightly sandy; some interbedded marl, marly limestone, and nodular limestone; sandstone lenses in northeast on Diablo Plateau.	130±-510	Widespread.
		-?-?-?-?-	Cox	Brown-weathering and brown-speckled sandstone, shale and siltstone, and limestone: shale and siltstone predominate in northwestern exposures, in Finlay Mountains; sandstone predominates in eastern exposures; sandstone and limestone are about equal in amount in southern exposures, in southern Quitman Mountains.	450-1,300±	Widespread.
		Trinity	Campagrande [3]	Generally limestone and marl in upper 200 ft; interbedded limestone, silt, sandy shale, sandstone, and conglomerate in lower part.	375-800±	North of railroads.
			Bluff Mesa [3]	Gray sandy limestone and less limestone, sandstone, and shale; many massive limestone beds.	1,080-1,475±	South of railroads.
			Yucca	Limestone, sandstone, quartzite, limestone-pebble conglomerate, and shale; conspicuous red and yellow beds; limestone predominates in northern exposures, sandstone predominates in southern exposures.	0-5,500+	South of railroads.
			Etholen [4]	Conglomerate, chiefly of limestone pebbles, cobbles, and boulders; scattered chert pebbles and local beds of chert-pebble conglomerate; some lenses of gray limestone.	700+	Etholen Knobs and Etholen Hill.
Cretaceous(?)	Lower		Torcer [4]	Impure limestone containing clay to sand-sized siliceous particles; some sandstone and shale; basal beds of quartzitic sandstone and some conglomerate chiefly of siliceous pebbles.	400±	Malone Mountains and west side of north end of Quitman Mountains.
Jurassic	Upper		Malone	Upper member: black limestone, generally sandy; some calcareous sandstone at base. Lower member: sandstone, siltstone and shale, limestone-pebble conglomerate, and limestone; all units thinly bedded; abrupt lateral changes in facies; irregular and discontinuous bodies of gypsiferous rock in basal and middle parts.	190-1,000±	Malone Mountains and west of north end of Quitman Mountains.
——Uncomformity——						
Permian	Leonard		Briggs [5]	Gypsum and interbedded irregular bodies and lenses of limestone and dolomite.	630+	Malone Mountains and west of north end of Quitman Mountains.
			Not named [5]	About 60 percent marlstone and 40 percent limestone, dolomitic rocks, and limestone-pebble conglomerate.	1,650+	Finlay Mountains.

[1] Top is at base of Devil Ridge thrust.
[2] Probable range.
[3] The order of these two formations in the table does not indicate stratigraphic sequence. They are equivalent in part at least.
[4] The order of these two formations in the table does not indicate a strict stratigraphic sequence. They may be equivalent in part.
[5] The order of these two formations in the table does not indicate stratigraphic sequence. They are equivalent in part at least.

area and are particularly prominent in the Finlay Mountains.

PERMIAN SYSTEM

CONTRASTING SEDIMENTARY FACIES

Rocks belonging to the Permian System are exposed only in the Malone and Finlay Mountains. The exposures are only 7 miles apart, yet the rocks are so different in facies and thickness that their relations are uncertain. The base of each sequence is concealed, and the top is truncated along an unconformity.

In the Finlay Mountains, the Permian beds are 1,650 feet thick. They were laid down as clastic sediments, mostly calcareous muds; marlstone accounts for 60 percent of the sequence, and the remainder is about equally divided between limestone and conglomerate. Marine invertebrate fossils that occur throughout the sequence are the basis for assigning these beds to the Leonard Series.

In the Malone Mountains, the Permian beds are 630 feet thick and consist dominantly of gypsum. The interbedded carbonate rocks are more commonly dolomitic than calcitic varieties. This sequence originated mostly as chemical precipitates. Marine invertebrate fossils characteristic of the Leonard Series occur in limestone at the base of the section in the Malone Mountains; the remainder is mostly unfossiliferous except for reeflike masses of possible algal origin in the upper part.

The gypsiferous sequence of the Malone Mountains is the Briggs Formation (Albritton, 1938). Because of the physical differences mentioned above, we treat the Leonard sequence of the Finlay Mountains as a unit separate from the Briggs, neither formally classified nor differentiated. The two sequences, however, appear to be at least partly contemporaneous.

LEONARD SERIES (UNDIVIDED) OF FINLAY MOUNTAINS

STRATIGRAPHIC SECTION

Rocks of Permian age crop out over an area of approximately 5 square miles in the western part of the Finlay Mountains. The dominant rock is a hard fine-grained mixture of carbonate minerals and clay, here termed a marlstone, which makes up most of the lower three-fourths of the exposed section. In the upper fourth the marlstone is interbedded with limestone in approximately equal amounts. Limestone conglomerate occurs from bottom to top of the sequence, although the thickest units are restricted to the lower 900 feet and the upper 200 feet.

Thicknesses of the lower marlstone units are difficult to measure because of disconnected outcrops and erratic original dips. As minimum thicknesses were assigned to these units, our estimate of 1,650 feet for the entire exposed sequence is also a minimum figure. An unknown thickness of beds is concealed at the base of the sequence and was eroded from the top prior to deposition of the Lower Cretaceous strata.

The sequence is highly variable in lithology. Limestone blends with limestone conglomerate both laterally and vertically. Most marlstones contain interbedded limestone and conglomerate. Bodies of conglomerate vary greatly in thickness within short distances and many end abruptly when traced along strike.

The following stratigraphic section was measured across the larger croppings of bare rock along traverse 1 shown on plate 1.

SECTION 1.—*The Leonard Series (undivided) in the Finlay Mountains*

[Western part of Finlay Mountains; traverse 1 shown on plate 1. Fossil identifications by G. A. Cooper, C. C. Albritton, Jr., L. G. Henbest, R. C. Douglass, Helen Duncan, and Ellis Yochelson]

	Thickness (feet)
Permian System—Leonard Series (undivided):	
23. Conglomerate, predominantly limestone pebbles and scattered pebbles of jasper, all set in a limestone matrix; grades laterally into pebbly limestone	12

SECTION 1.—*The Leonard Series (undivided) in the Finlay Mountains*—Continued.

	Thickness (feet)
Permian System—Leonard Series (undivided):—Con.	
22. Limestone, pebbly, gray, weathering brownish; contains numerous bryozoans, crinoid stems, horn corals, and fusulinids	18
21. Marlstone, silty, poorly exposed	12
20. Limestone, gray, in layers about 1 ft thick; abundantly fossiliferous—contains fusulinids, brachiopods, solitary corals, and large crinoid stems	18
19. Conglomerate, well-rounded limestone pebbles averaging about one-half inch in diameter and scattered chert pebbles; matrix of rounded limestone grains and occasional fusulinid tests, cemented by finely crystalline calcite	80
18. Marlstone, gray	26
17. Limestone, gray, dolomitic, weathering brownish in lower part and gray in upper; scattered chert nodules enclose and replace fossils; abundantly fossiliferous—contains fusulinids, small horn corals, brachiopods (*Enteletes dumblei* Girty and *Prorichthofenia teguliferoides* King), and crinoid stems	17
16. Conglomerate of limestone pebbles and scattered chert pebbles; grades laterally into finely crystalline pebbly gray dolomitic limestone containing many fossils like those of unit 17	19
15. Limestone, gray, crinoidal	8
14. Marlstone, gray, silty	72
13. Limestone, gray, finely crystalline; contains abundant bryozoans; fragments of crinoid stems in basal layers	37
12. Marlstone, silty; contains interbedded thin layers of dark-gray limestone	36
11. Limestone, dark-gray, finely crystalline; mostly massive, locally laminated; contains numerous brachiopods: *Rhipidomella hessensis* King, *Composita mexicana* (Hall), *Leptodus* sp., *Wellerella elegans* (Girty), *Hustedia meekana* (Shumard), and *Prorichthofenia* cf. *P. likharevi* King; scattered ammonoids: *Perrinites hilli* (Smith) and *P. hilli tardus* Miller and Furnish?; abundant large crinoid stems, many with cirri	35
10. Marlstone; contains interbedded lentils of limestone; poorly exposed	14
9. Limestone, gray, massive, finely crystalline	20
8. Limestone, gray, thinly bedded, finely crystalline; contains shaly partings; weathers brown; contains abundant fusulinids: *Pseudofusulina* sp. and *Parafusulina* sp. (USGS f9687); sponges: *Heliospongia* sp.; bryozoans: *Fistulipora* sp.,*P roretepora* sp., and *Septopora* sp. (USGS 14590–PC); brachiopods: *Orbiculoidea* sp., *Cancrinella* sp., *Dyoros subliratus* (Girty), *D.* sp., *Kozlowskia sublaevis* (King), *Marginifera? manzanica* Girty, *M.?* sp., *Linoproductus* sp., *Antiquatonia hessensis* King, *Composita* sp., *Neospirifer infraplicus* King; pelecypods: *Aviculopinna* sp. (USGS 14590–PC); gastropods: *Euphemites* sp. (USGS 14590–PC); and cephalopods *Propinacoceras knighti* Miller and Furnish, *Medlicottia costellifera?* Miller and	

SECTION 1.—*The Leonard Series (undivided) in the Finlay Mountains*—Continued.

Permian System—Leonard Series (undivided):—Con.	*Thickness (feet)*
Furnish, and *Perrinites hilli tardus* Miller and Furnish	8
7. Marlstone, gray; contains thin interbeds of impure limestone toward top and interbedded limestone cobble conglomerate, calcitic sandstone, and pebbly limestone toward base; poorly exposed; upper few feet contains fossils like those of unit 8; scattered leaves of *Pecopteris* sp., *Callipteris* sp., *Glenopteris*? sp., and *Sphenophyllum*? sp. occur at horizons 20 to 40 ft below top	340
6. Conglomerate, largely of rounded pebbles of gray limestone and scattered pebbles of chert; in beds several feet thick	144
5. Marlstone and calcitic sandstone interbedded	21
4. Limestone, gray, crystalline, containing crinoid stems	45
3. Conglomerate, largely of rounded limestone pebbles and scattered pebbles of chert; matrix has texture of very coarse sand, consisting predominantly of rounded bits of limestone; contains *Hustedia hessensis* King	31
2. Marlstone, medium-gray, dolomitic; weathers yellowish brown or olive gray; contains interbedded limestone pebble conglomerate, calcitic sandstone, and dark-gray limestone. Marlstone shows gigantic crossbedding, especially toward top of unit. Limestone beds commonly fossiliferous, containing fusulinids: *Parafusulina*? sp. aff. *Schwagerina hessensis* Dunbar and Skinner, *Schwagerina diversiformis* Dunbar and Skinner, and *Parafusulina*? sp. (USGS f9688); bryozoans: *Proretepora* sp. (USGS 14592–PC); and brachiopods: *Dyoros subliratus* (Girty), *Linoproductus* sp., *Stenoscisma venusta* (Girty), and *Phricodothyris* sp. Unit poorly exposed; minimum thickness	450
1. Conglomerate, predominantly of well-rounded pebbles, cobbles, and boulders of limestone and scattered pebbles of chert, all set in silty or sandy matrix cemented by calcite; coarsens toward base, where some beds contain boulders as much as one-half foot across; upper part locally fills channels in marlstone or interfingers with marlstone; base not exposed	190
Total exposed thickness	1,653

Part of the Permian sequence in the Finlay Mountains consists of marlstone, which in previous reports has been called "shale." Though thinly bedded, platy, and laminated, the marlstone is well indurated and breaks across the laminae unlike ordinary shale. It is a mixture of clay and carbonate in roughly equal proportions. Formerly it must have been much like the marls and marly limestones common in the Cretaceous System of northern Texas. Accordingly, this rock is classed as marlstone in this report.

Sequences of marlstone are from 11 to 450 feet thick, the thicker units occurring in the lower 900 feet of the section (fig. 2). Weathered surfaces are characteristically light gray, although some have olive, brown, or yellow casts. Outcrops of marlstone may be distinguished at a distance from darker units of limestone or conglomerate by their prevailingly light-gray color.

Bedding planes marked by cleavage are ½ to 3 inches apart. The marlstone between the planes consists of alternating dark and light laminae that range from 0.15 mm to 1 cm in thickness. Arrangement of the thin and thick laminae appears to be unsystematic, except that a few specimens show a pattern of relatively thick light laminae separated by four or five pairs of thin light and dark laminae.

At many horizons the marlstone coarsens and changes to clastic limestone that has the texture of fine-grained sandstone. In a few places it blends with limestone conglomerate through pebbly marlstone, although the interbedded conglomerate lies mostly against marlstone along sharp contacts (fig. 3). Finely crystalline black limestone in layers a foot or less thick locally forms a quarter or half of the marlstone sequences, which are several tens of feet thick.

At intervals throughout the lower third of the section the marlstone is crossbedded, though on a scale so large as to be undetected in small exposures (fig. 4). The crossbedded units are commonly several tens of feet thick. The contacts are smooth, cleanly truncating beds below and paralleling beds above. Divergences in apparent dips of adjacent units are as much as 15° and in strike are between 45° and 75°. In places, contorted layers as much as 2 feet thick lie between parallel foreset beds. Within these, the marlstone has been thrown into complex folds which are recumbent or are overturned down the dip of the bedding. In places, the folds appear to have been sheared off by the downward sliding of the beds above. Clearly these deformed layers show the effects of unconsolidated sediments gliding down foreset slopes.

Analyses by Guerrero and Kenner (1955, p. 49) of three marlstone samples (A–91, 157a, and 157b, table 3) from unit 2 of the section show that all are dolomitic and contain 7 to 9 percent magnesium carbonate.[1] The insoluble residue ranges from 35 to 45 percent, most of which is clay; in two of the three

[1] We follow the usage of Pettijohn (1957, p. 418) in classifying carbonate rock, based on the relative percentages of calcite and dolomite in the carbonate fraction. According to this system, limestone contains more than 95 percent calcite, magnesian limestone between 90 and 95 percent, dolomitic limestone between 50 and 90 percent, calcitic dolomite between 10 and 50 percent, and dolomite less than 10 percent. The name dolomite thus refers in some places to a rock, in others to a mineral, but the meaning intended will be clear from the context.

FIGURE 2.—Thinly bedded Permian marlstone, 2.7 miles east of Wilkie Ranch house, in Finlay Mountains.

samples, clay slightly exceeds calcium carbonate. Mixed with the clay is 7 to 8 percent quartz silt, in grains or as aggregates of grains cemented by silica. The aggregates occur as solid pellets and hollow spheres and possibly represent animal castings and foraminiferal tests, respectively. Crystals of authigenic gypsum and minute botryoidal bodies of an iron mineral, probably hematite, are fairly common.

In thin section the lamination is seen to be an alternation of fine and coarse layers. The fine layers are cryptocrystalline mosaics, presumably of intergrown carbonate and clay minerals in which are set grains of angular quartz silt. In the coarse layers the grains exceed the matrix in volume and consist not only of quartz but also of limestone in rounded silt and fine-grained sand sizes (fig. 5). An increase in the amount of limestone grains causes the rock to become a calcareous siltstone or sandstone.

Fossils are less abundant in the marlstone than in the other rocks of the unit and were not found in the conspicuously crossbedded units. Evenly stratified marlstone is also mostly barren except where interbedded with limestone; there it contains numerous excellently preserved fossils, especially small productid and chonetid brachiopods. Minor elements of the fauna are bellerophontid gastropods, Pinnacea pelecypods, and occasional small nautiloids and ammonoids; fusulinids are apparently lacking. At several horizons fragmentary but well-preserved plants are mingled with the shells of these benthonic marine organisms. Fossils are much more abundant in the limestones interbedded with the marlstone and include types which are either not present in the marlstone or are very scarce. The limestones contain lacy cryptostome bryozoans, massive trepostome bryozoans, large productid brachiopods, and fusulinids.

The marlstone is broken everywhere by joints trending in two or more directions, spaced at intervals of a few inches. The joints are accentuated by weathering, and the marlstone is generally mantled by a rubble of blocks and splinters.

Conglomerate made up of rounded pebbles, cobbles, and occasional boulders of limestone occurs at irregular intervals from the bottom to the top of the section. Most conglomerate units are only a few feet or a few tens of feet thick, but some attain 190 feet in thick-

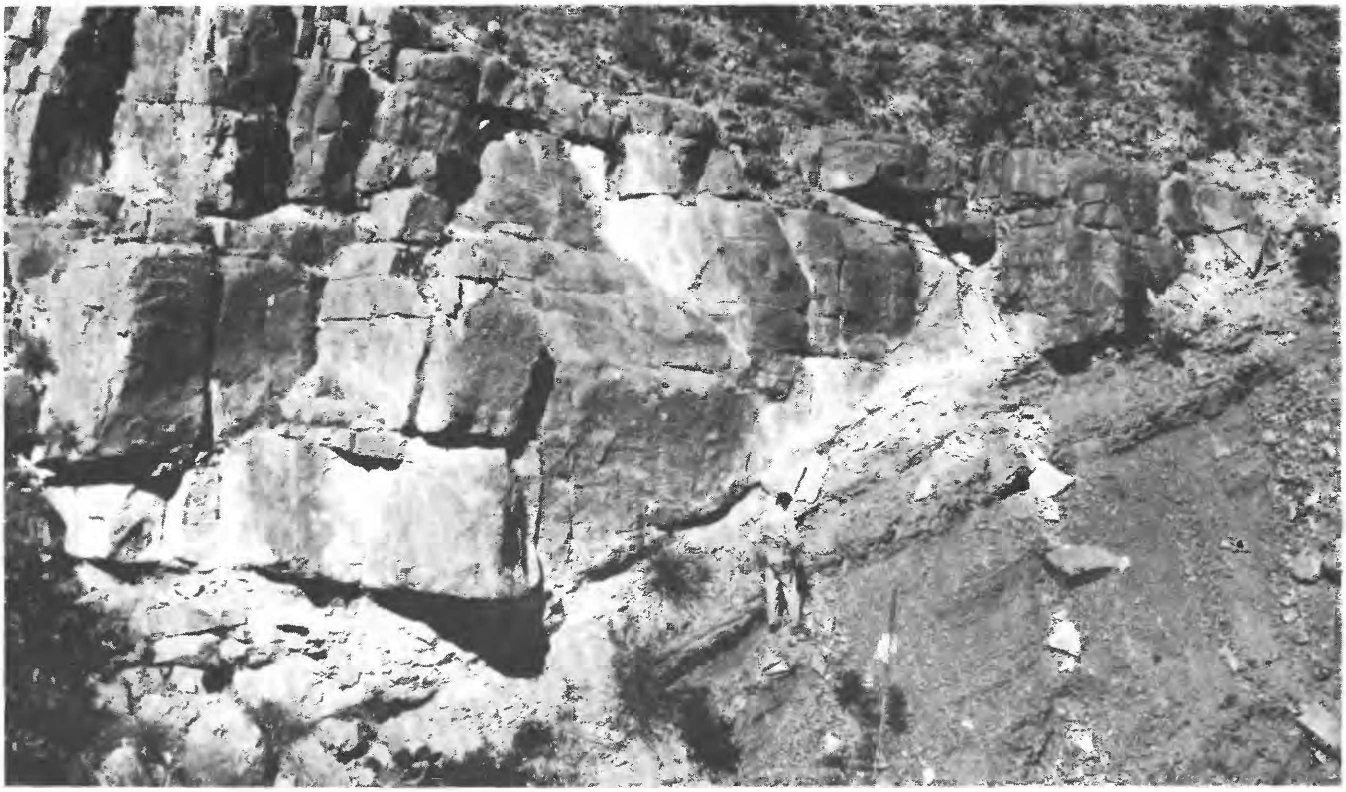

FIGURE 3.—Limestone conglomerate (left) abutting against foreset slope of marlstone. Leonard Series in Finlay Mountains, 2.3 miles east of Wilkie Ranch house.

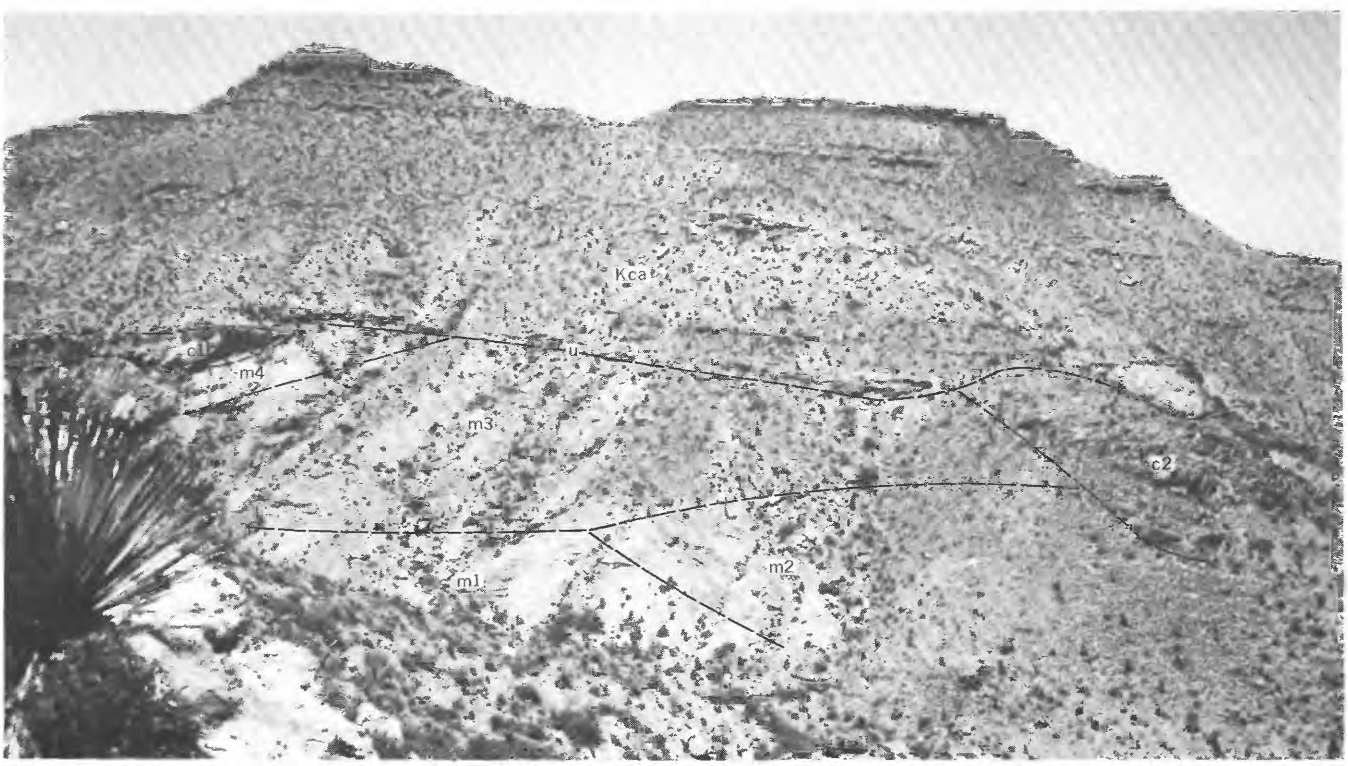

FIGURE 4.—Basal part of Campagrande Formation (Kca) resting on marlstone and conglomerate of Permian age along unconformity (*u*). Four units of marlstone (*m*1–*m*4) display large-scale crossbedding. Conglomerate at left (*c*1) is interbedded with marlstone; conglomerate at right (*c*2) fills channel in marlstone. Local relief in this view about 500 feet. In Finlay Mountains, 1.8 miles southwest of Cavett Ranch house.

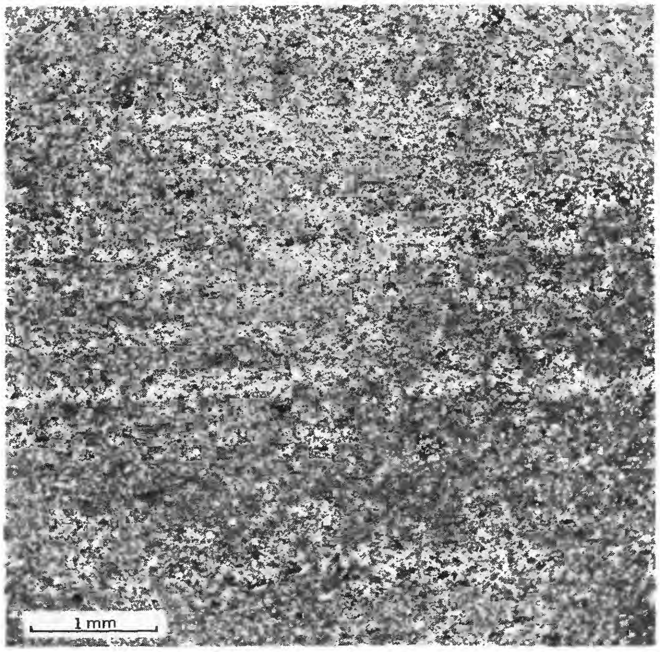

FIGURE 5.—Laminated dolomitic marlstone from Leonard Series in Finlay Mountains. The tiny light-gray grains are quartz silt, and the dark flecks, mostly hematite. The cryptocrystalline matrix is a mixture of clay, calcite, and dolomite.

ness. Several are interbedded with limestone, but most, including the thickest, are associated with marlstone. In either association the conglomerate bodies are highly irregular, very commonly grade laterally or vertically into pebbly limestone and thence to limestone without pebbles, abut abruptly against slopes of crossbedded marlstone, or form channel fillings in the marlstone.

Seen from a distance, conglomerate beds are generally indistinguishable from the limestone beds, as both weather medium gray to grayish orange and form ledges, bluffs, and cuesta caps of similar appearance. In some layers both pebbles and matrix are of approximately the same hue, but in most the limestone clasts have several textures and colors, which give the rock a mottled appearance. Some of the conglomerates are further variegated by brownish chert or reddish-brown jasper fragments.

Bedding surfaces are discontinuous partings irregularly spaced between 1 and 10 feet apart. They tend to be parallel throughout any particular body of conglomerate, but in detail many are curved and otherwise irregular. In some places irregularity is increased by stylolites along the bedding surfaces.

Fragments in the conglomerate range from particles no larger than sand grains to cobbles 150 cm across, but most are pebbles 1 to 2.5 cm across. Most are of finely crystalline gray or brownish-gray limestone that weathers gray or grayish orange. Chert, jasper, and quartzite are sparsely represented, and oolitic limestone is uncommon. Fossil shells and fragments are mingled with the pebbles in varying amounts. Fusulinid tests, both whole and fragmentary, are common and in places fill most of the space between pebbles. They are associated with abundant crinoid stems, tiny fragments of bryozoan colonies, and brachiopod and pelecypod shells.

All inorganic constituents larger than sand grains are variously rounded; relatively few have shapes suggestive of original joint blocks and those that do generally have smooth and curved edges. Most of the pebbles are triaxial ellipsoids and have broadly or narrowly rounded edges. The two larger dimensions generally lie in the plane of the bedding, although pebbles in some layers have an imbricate arrangement. The harder pebbles of jasper and chert are no less rounded than are the average pebbles of the softer limestone.

Microscopic examination reveals that pebbles and fossils alike are firmly cemented by calcite, which forms uneven microcrystalline and cryptocrystalline mosaics (fig. 6). This cement encloses scattered angular grains of quartz silt and rounded sand-sized grains of both quartz and limestone. The original nature of the interstitial material is problematical, but it may have been recrystallized from calcareous

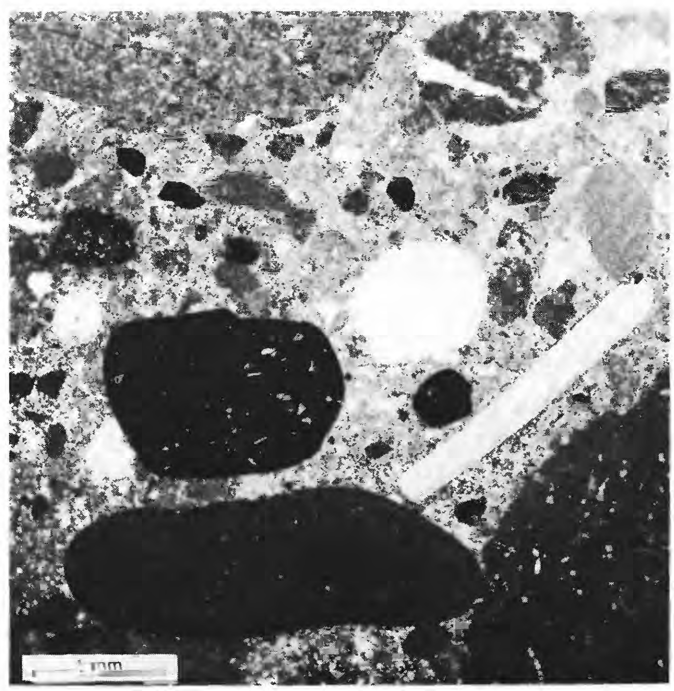

FIGURE 6.—Limestone conglomerate from Leonard Series in Finlay Mountains. Rounded particles of limestone, as small as fine sand grains, are set in mosaic of microcrystalline calcite. Rodlike object is probably an echinoid spine.

mud. Many of the fusulinid tests have lost part of their internal structure by the growth of calcite crystals. Limestone pebbles are intergrown along stylolitic seams.

Limestone forms beds throughout the Leonard Series of the Finlay Mountains. Those in the lower part are discontinuous and relatively inconspicuous layers embedded in marlstone, but in the upper fourth of the series they form prominent ledges between 5 and 35 feet thick. The rock is dark gray on fresh surfaces but weathers to lighter grays and grayish browns; a few beds weather grayish orange. Most of the limestone units contain bedding planes half a foot to several feet apart. These are mostly parallel but are irregular or undulatory in detail. Some are marked by shale partings.

Whole or fragmentary fossils, preserved in calcite or replaced by silica, commonly account for as much as half the limestone. In thin section they are seen to lie in microcrystalline or cryptocrystalline calcite intergrowths associated with minor amounts of clay in an uneven mosaic. A few uncommonly small oolitic bodies that have concentric structure and are about one-tenth of a millimeter in diameter are also present.

On table 3 is shown the composition of four limestone samples (Nos. A–93, 139, 143, and 145) from the upper part of the section. The acid-soluble matter in these has a narrow range between 94.6 and 96.8 percent; in two samples the magnesium carbonate is sufficiently great to make the rock a dolomitic limestone. Insoluble residue in the calcitic limestones is principally silicified shell fragments, and half or more of that in the dolomitic limestones is clay. Insoluble particles of silt size or larger are mostly silicified fragments of crinoid stems and brachiopods.

Many rounded limestone pebbles are scattered through the limestone, and gradations between limestone and limestone conglomerate are common. The abundant pebbles and shell fragments suggest that much of the limestone is of clastic origin.

In the purer limestome beds, brachiopods, bryozoans, and crinoid stems are crowded together profusely. The crinoids were broken up before they were incorporated in the rock; the stems are short segments a little longer than thick, and calices are absent. In contrast, some of the smaller brachiopod shells were buried with their valves articulated, and the tiny productids retained all their fragile hollow spines. Fusulinids are associated in places with the other fossils but are much more abundant in the more clayey limestones, locally to the exclusion of other organic remains. In places, they lie in parallel orientation (fig. 7), but random orientation seems to be more common.

Fossils are silicified on weathered surfaces of limestone, where they stand in relief, and commonly to depths of about 2 inches below the surface. According to Ham (1943) the replacement of original calcium carbonate by silica is an effect of weathering, although probably under climatic conditions more humid than those now prevailing. The silicified fossils lost little of their internal structure by replacement; the alveolar fusulinid walls were about as well preserved by the silica as by calcite in different parts of the same rock.

Nodular masses of brownish-weathering gray chert occur in some of the limestone beds in the upper 400 feet of the section. Their shapes are irregular and have longer dimensions of several feet in the plane of the bedding. Borders of the nodules are sharp and

TABLE 3.—*Analyses of carbonate rocks from the Leonard Series (undivided) of the Finlay Mountains*

[R. G. Guerrero, analyst (Guerrero and Kenner, 1955, table 4, p. 49)]

Specimen			Analysis (percent)				Remarks
No.	Classification	Stratigraphic unit in measured section 1	Acid insoluble	$CaCO_3$	$MgCO_3$	Nondetermined acid soluble, by difference	
A–93	Dolomitic limestone.	17	3.20	90.61	4.81	1.38	Contains abundant tests of fusulinid foraminifers with chambers filled by coarsely crystalline calcite.
139	do	16	3.17	84.65	8.91	3.27	About half the insoluble residue is clay; the remainder is silicified shell fragments and scattered grains of quartz sand.
143	Limestone	13	3.18	92.36	2.03	2.43	Residue consists mainly of silicified shells and shell fragments.
145	do	11	5.42	86.49	.90	7.19	Residue is mostly silicified remains of brachiopod shells, echinoid(?) spines, and crinoid stems.
A–89	Dolomitic marly limestone.	2	12.67	69.44	10.02	7.87	Insoluble residue mostly clay; mineral dolomite occurs as minute euhedra in calcite mosaic. Authigenic gypsum crystals and hematite(?) spherulites abundant.
A–91	Dolomitic marlstone.	2	36.43	46.06	9.29	8.22	Insoluble residue mostly clay, contains about 5 percent angular quartz silt. Authigenic gypsum and pale blue botryoidal chalcedony are common accessories.
157a	do	2	41.91	41.88	8.16	8.05	
157b	do	2	44.22	41.57	7.15	7.06	Insoluble residue mostly clay, but contains considerable quartz silt as grains and aggregates.

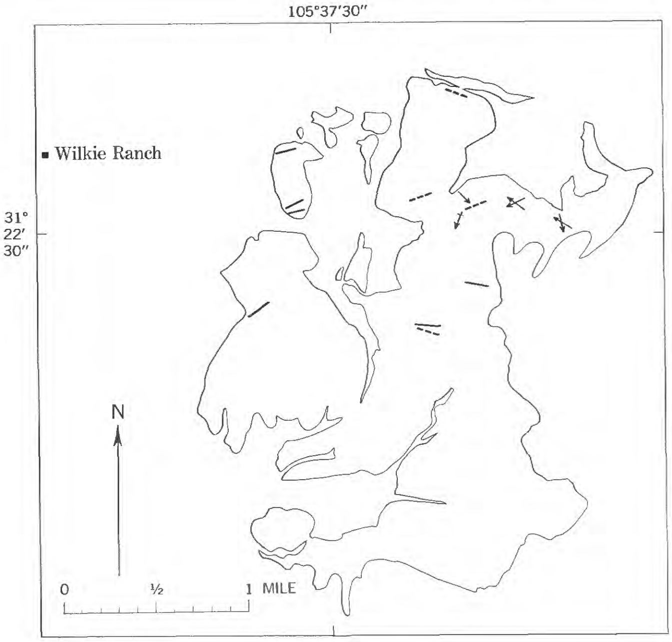

FIGURE 7.—Outcrop area, rocks of Permian age in Finlay Mountains, showing relations between certain primary structures. Solid lines indicate long axes of fusulinid tests where these tests show parallel orientation. Dashed lines show bearings of buried channels filled with conglomerate. Arrow with crossbar shows direction of currents, indicated by imbricate arrangement of pebbles in conglomerate. Other arrows point downdip of foreset beds in marlstone sequences.

commonly extend part way across individual fossils (fig. 8). Fusulinids are preserved in great numbers in some of the chert nodules. Thin sections of fusulinid limestone and chert show that silica first replaced the walls of the foraminiferal tests and then the surrounding calcitic matrix. Evidently the chert originated after, though not necessarily long after, the deposition of calcareous muds that later solidified to form the limestone beds.

The limestone beds cap several small cuestas in the western part of the Finlay Mountains. Surfaces are exceptionally rough, for they not only are etched into pits and furrows by rainwater but also are studded by silicified fossils.

FOSSILS AND CORRELATION

In early reports (Streeruwitz, 1891, p. 678, and Richardson, 1904, p. 35–36) these rocks were assigned to the Carboniferous System and were correlated with the Hueco Limestone. Richardson (1904, p. 35–36) listed six species of invertebrate fossils provisionally identified by G. H. Girty, who suspected that they belonged to a fauna younger than that of the Hueco Limestone at the type area. More extensive collections were made later by R. E. King (1930, p. 17, pl. 30), who identified the brachiopods; Dunbar and Skinner (1937, p. 725) identified the fusulinids; and Miller and Furnish (1940, p. 16) identified the ammonoids. The collections came from a zone corresponding approximately to units 7 and 8 of our measured stratigraphic section 1. The fossils suggest a Leonard age for these units, but no data were obtained for the 600 feet of strata below these units, nor the 400 feet above them.

Fossils collected during the present investigation suggest that all the rocks of Paleozoic age in the Finlay Mountains belong to the Leonard Series. Fossils were identified by G. A. Cooper, L. G. Henbest, R. C. Douglass, Helen Duncan, Ellis Yochelson, and C. C. Albritton, Jr. The fauna are listed in stratigraphic section 1.

The brachiopods include *Dyoros subliratus* (Girty) and *Stenoscisma venusta* (Girty), two species characteristic of the Leonard, which occur in limestone 190 feet above the base of the exposed section. Two other brachiopods, *Enteletes dumblei* Girty and *Prorichthofenia teguliferoides* King, both common in the Leonard Series in the Glass Mountains 150 miles southeast of the report area, occur within 160 feet of the top of the Finlay Mountains section.

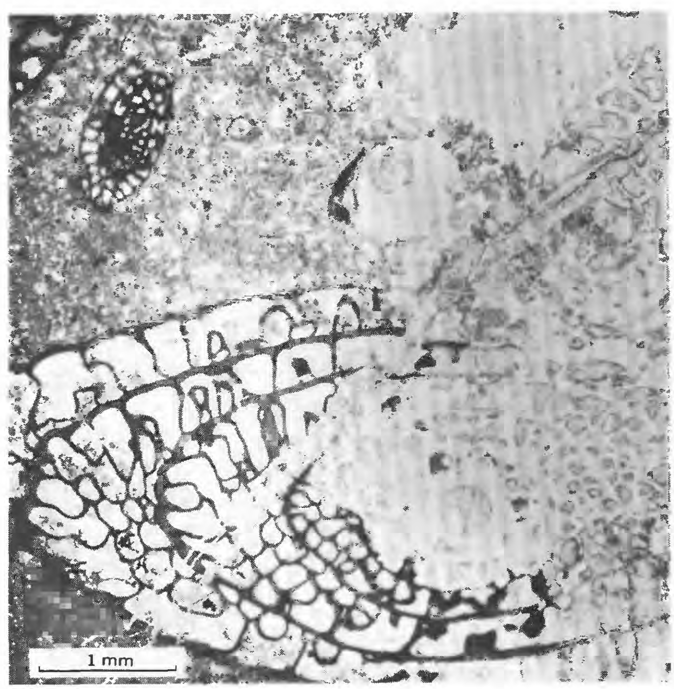

FIGURE 8.—Cherty limestone from Leonard Series of Finlay Mountains. Darker area to left is uneven mosaic of calcite (mostly cryptocrystalline); lighter area to right is microcrystalline chert which has partly replaced the limestone. Test of large fusulinid is about half replaced by chert, although calcite remains in the proloculus and in many of the chamberlets. A veinlet of calcite crosses both the limestone and the chert.

The ammonoids identified by Miller and Furnish from R. E. King's collection from unit 8 of our section include *Propinacoceras knighti*, *Medlicottia costellifera?*, and *Perrinites hilli* var. *tardus*, which also are characteristic of the Leonard.

The fusulinids include: *Parafusulina?* sp. aff. *Schwagerina hessensis* Dunbar and Skinner; *Schwagerina diversiformis* Dunbar and Skinner; *Parafusulina?* sp. (USGS 9688) from the lower part of the section (unit 2); and an undescribed species, 3 to 4 mm in diameter and as much as 15 mm long, transitional from *Pseudofusulina* to *Parafusulina* (USGS 9684) from unit 22, a limestone 12 feet below the top of the section. The fauna, according to Henbest and Douglass, is probably of Leonard age, although an earlier age, possibly extending back to Wolfcamp, cannot be ruled out on evidence of the larger Foraminifera alone. The upper part of the section, then, containing fusulinids no younger than Leonard age and above a zone containing characteristic Leonard brachiopods and cephalopods is probably of Leonard age.

The basal 190 feet of the exposed section (unit 1) is a conglomerate in which no fossils have been found. Although there is no evidence that part of this unit might not be as old as the Wolfcamp Series, its upper part, at least, interfingers with marlstone and conglomerate containing brachiopods typical of the Leonard and fusulinids that are strongly suggestive of Leonard age.

BRIGGS FORMATION

DEFINITION

The name Briggs Formation was given by Albritton (1938, p. 1753) to 630 feet of interbedded limestone, gypsum, and dolomitic rock forming approximately the lower third of the strata in the Malone Mountains and in the Malone Hills east of Torcer. The type locality is at Gypsum (formerly Briggs) switch on the Southern Pacific railroad, where the rocks are excellently exposed in quarries and on the hills nearby. Only about half the total thickness is exposed at the type locality. Previous and present stratigraphic terminologies are given in figure 9.

LITHOLOGY

One-half to two-thirds of the Briggs Formation is gypsum. Limestone and dolomite are interbedded with the gypsum in lentils a fraction of an inch thick and in lenses and irregular bodies as much as 200 feet thick. Three of the larger bodies are designated as members, but it is necessary to consider the entire area of outcrop to determine relations between them (fig. 10).

The gypsum is weakly resistant to erosion and forms valley floors and lower hill slopes, but its outcrops are conspicuous because of their extreme bareness and dazzling reflections in bright sunlight. It is best exposed in the quarries at Gypsum switch.

The gypsum is white or very light gray and consists of interlocking selenite crystals generally less than a millimeter long and scattered larger crystals which form local layers as much as an inch thick. Gypsum of the Briggs is remarkably free of detrital matter, except for tan or brownish ferruginous streaks.

Small bodies of limestone and dolomite occur throughout the gypsum. Some of them are lenses several feet wide and three or four times as long as thick. Some of the lenses appear to have been deposited almost in their present form, whereas others represent continuous beds that were thickened by isoclinal folding (fig. 11). The thinner dolomite beds are complexly contorted, as a result partly of expansion due to alteration of primary anhydrite to selenite and partly of folding and thrusting. A representative dolomite specimen contains 48.70 percent $CaCO_3$, 43.96 percent $MgCO_3$, and 6.3 percent insoluble residue (Guerrero, 1952).

BLACK LIMESTONE MEMBER

The black limestone member, 150 feet thick, is exposed in a single small area at the northwest end of Malone Hills and is the oldest exposed part of the Briggs Formation. The rock appears black in contrast with the overlying gypsum, but actually it is brownish gray to dark gray. It is finely crystalline limestone, contains local nodules of chert, and almost everywhere has veinlets of milky calcite. Silicified solitary corals and other invertebrate fossils weather in relief and are fairly abundant at certain horizons. Chemical analysis (by R. G. Guerrero) of a representative sample indicates nearly 83 percent $CaCO_3$, 1 percent $MgCO_3$, and 15 percent insoluble material, mostly clay.

In thin section, the limestone is seen to consist of numerous fossil fragments set in an uneven-grained microcrystalline and cryptocrystalline mosaic of calcite crystals. Many of the brachiopod shells retain minute details of their original structure (fig. 12). Other shell fragments are replaced by calcite, either as single crystals that preserve relicts of the original structure or as coarsely crystalline intergrowths in which no vestige of original structure remains.

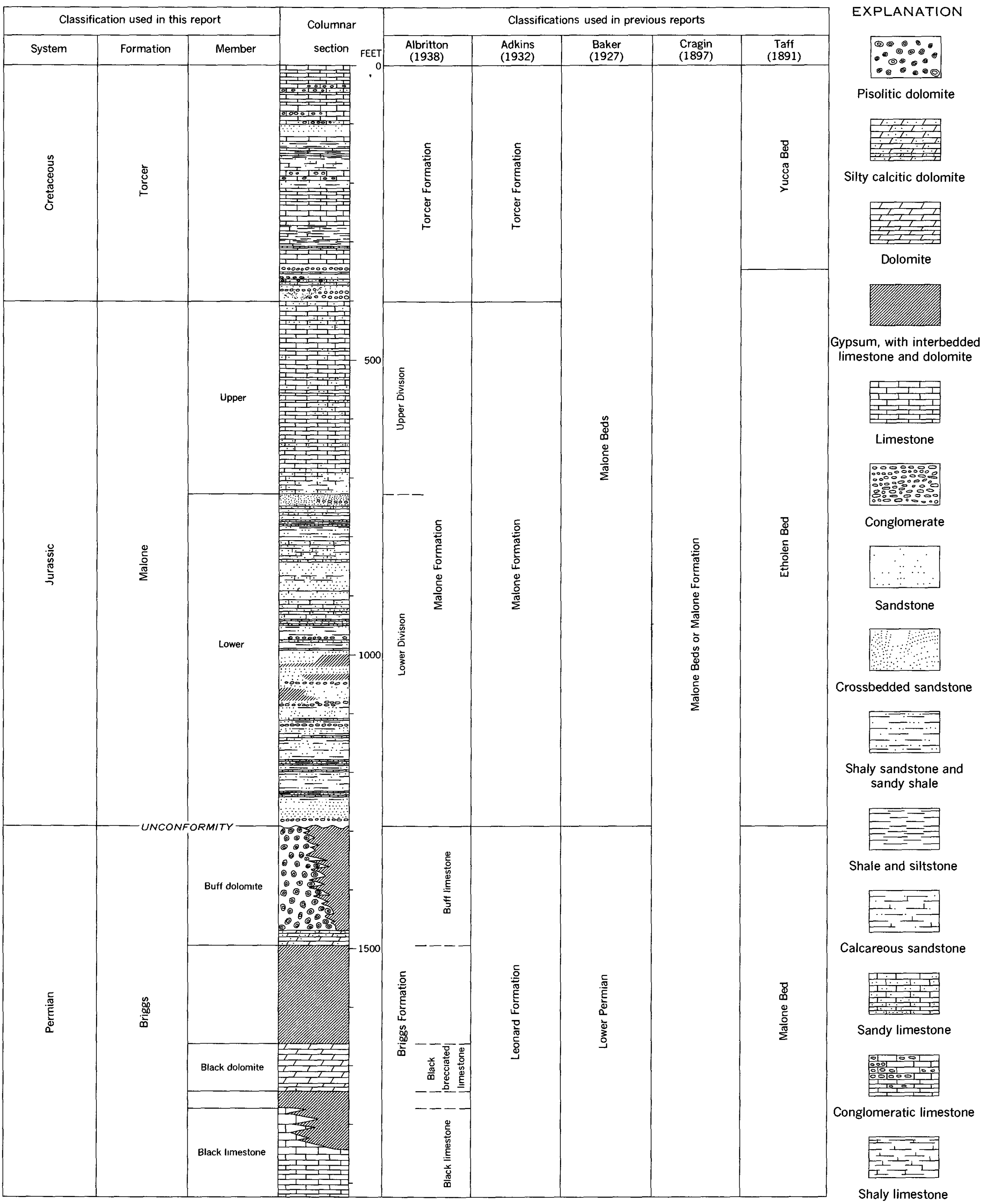

FIGURE 9.—Columnar section of consolidated rocks in the Malone Mountains and Malone Hills, comparing stratigraphic names used in this report with names used in previous reports.

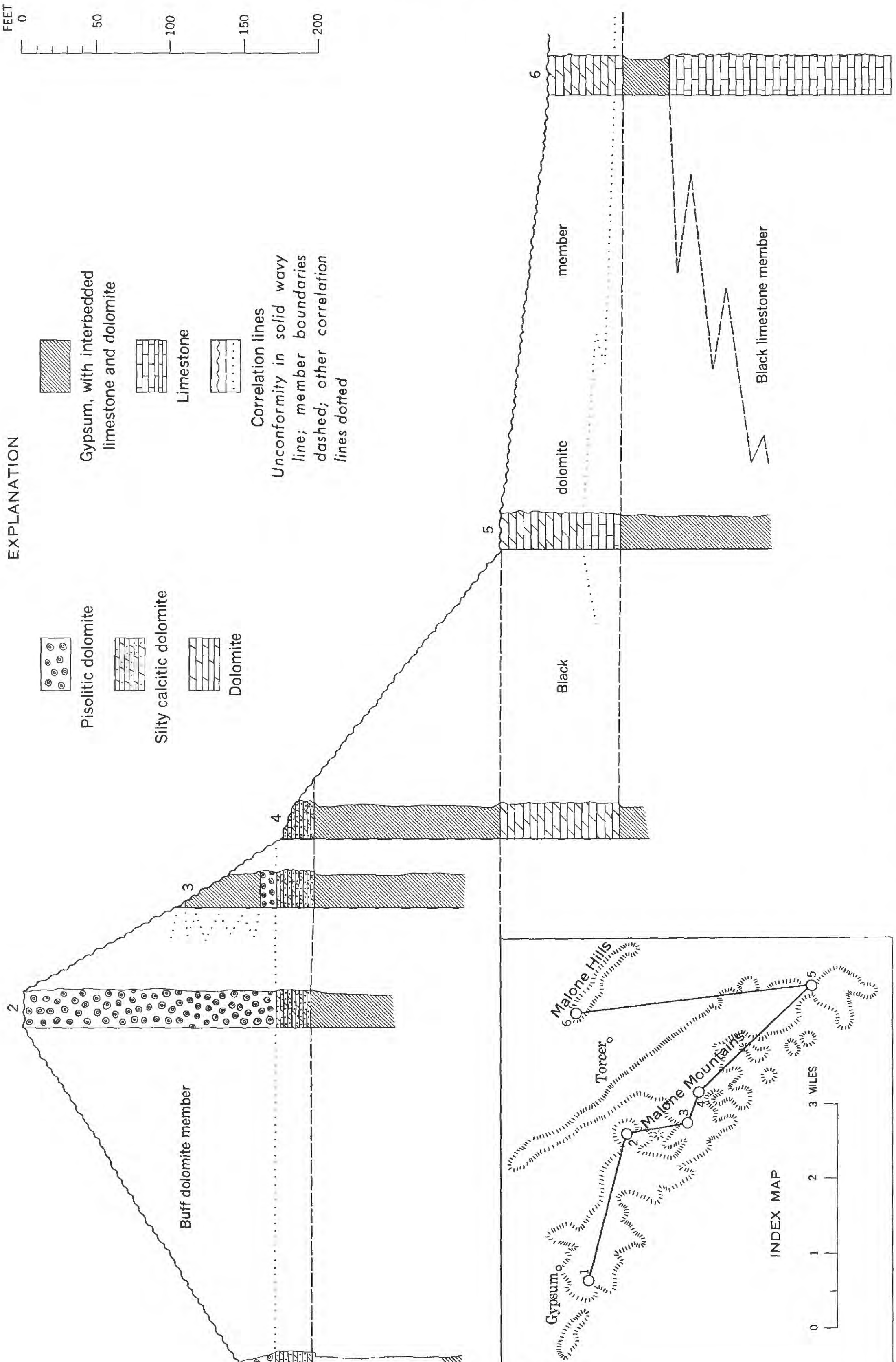

FIGURE 10.—Stratigraphic sections of the Briggs Formation in Malone Mountains and Malone Hills.

FIGURE 11.—Contorted stratum of dark-gray dolomite embedded in gypsum of Briggs Formation, along Arroyo Balluco, Malone Mountains.

BLACK DOLOMITE MEMBER [2]

This member is characteristically a finely crystalline dark-gray dolomite in beds several inches to several feet thick and is commonly laminated between the principal bedding planes. It consists of microcrystalline and cryptocrystalline intergrowths of mineral dolomite that enclose scattered and randomly distributed quartz grains. Stylolitic veinlets are common and accentuate the banded appearance of the rock. Analyses of three specimens indicate that the compositions of the soluble fractions closely approach the composition of mineral dolomite. (See table 4.)

In places, the black dolomite member contains small masses of breccia (fig. 13), which have sharp contacts with the dolomite and probably formed from collapse accompanying solution of underlying gypsum. The breccia formed before the Malone Formation of Late Jurassic age was deposited, as blocks of breccia occur as boulders in the basal conglomerate of the Malone.

Pale-brown to gray microcrystalline limestone underlies the dolomite in places and locally grades laterally into fine-grained calcareous sandstone containing angular quartz grains.

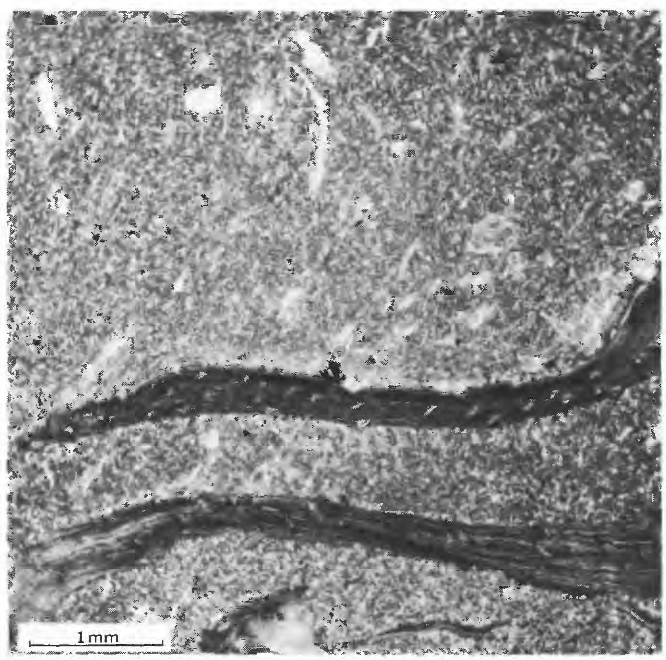

FIGURE 12.—Limestone from the black limestone member of the Briggs Formation, Malone Hills. The rock consists largely of microcrystalline and cryptocrystalline calcite enclosing fragments of brachiopod shells (fibrous bands) and other fossils.

[2] This is the same as the black brecciated limestone member of Albritton (1938, p. 1755). Although both limestone and dolomite are present, our investigations indicate that dolomite is the characteristic and more abundant type of rock.

TABLE 4.—*Analyses of carbonate rocks from the black dolomite member of the Briggs Formation*

[R. G. Guerrero, analyst (Guerrero and Kenner, 1955, table 3, p. 48)]

Specimen	Classification	Locality	Acid insoluble	$CaCO_3$	$MgCO_3$	Nondetermined acid soluble, by difference	Remarks
A-14	Dolomite	Southeast end of Malone Mountains.	5.17	52.02	41.77	1.04	Dolomite crystals form uneven-grained microcrystalline mosaic viewed in thin section. Scattered grains of quartz account for considerable part of insoluble residue.
A-84	do	Southeast end of Malone Mountains directly west of U.S. Highway 80.	1.02	54.24	44.13	.61	Dark material of unknown composition, concentrated along stylolitic cracks, gives rock laminated appearance.
A-83	do	Northwest end of Malone Hills.	5.00	53.27	40.62	1.11	Rock shows spongy texture, possibly relict of algal structure.

FIGURE 13.—Breccia in black dolomite member of Briggs Formation, southeast end of Malone Mountains, 1,200 feet north of Hilltop Cafe.

BUFF DOLOMITE MEMBER

The buff dolomite member, which is the buff limestone member of Albritton (1938, p. 1755), is a complexly interbedded sequence of dolomite, limestone, and gypsum and has a maximum measured thickness of 200 feet. The top is eroded, and in part of the Malone Mountains the entire member is lacking.

The most persistent part of the member is a basal sequence of buff-weathering, silty, finely crystalline calcitic dolomite about 25 feet thick. The rock is veined milky dolomite in most places and contains scattered chert nodules. In thin section the dolomite is seen to contain as much as 30 percent angular quartz silt set in an uneven microcrystalline mosaic of dolomite and calcite crystals (fig. 14).

In some places the basal dolomite is overlain by irregular bodies of massive gray oolitic and pisolitic dolomite. Most of these bodies are less than 25 feet thick; a few are as much as 170 feet thick. The pisolitic dolomite interfingers laterally with gypsum and apparently forms irregular prominences built up from a platform of the basal dolomite.

The oolites and pisolites are between half a millimeter and one centimeter in diameter. In some, the internal structure was largely destroyed by recrystallization, and in others, fractures were healed with calcite veins (fig. 15). In places, the oolites are firmly

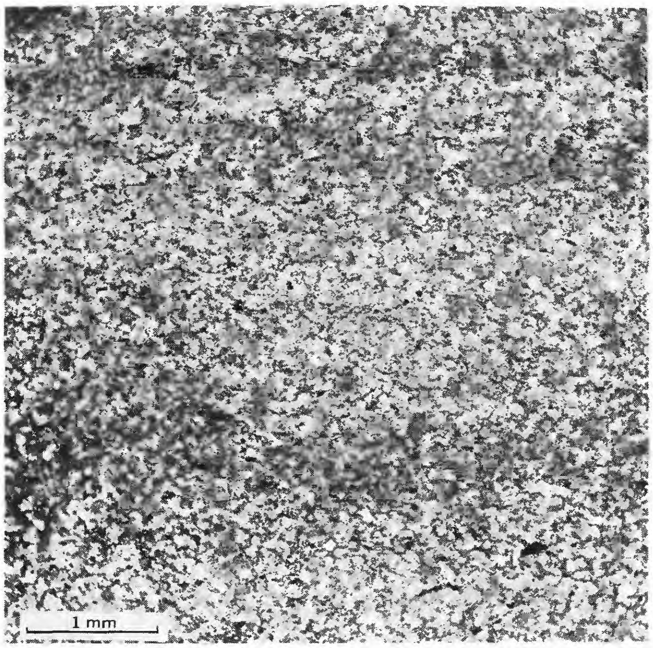

FIGURE 14.—Silty calcitic dolomite from buff dolomite member of the Briggs Formation, Malone Mountains (1.8 miles S. 62° W. of Torcer station). Light-colored spots are grains of quartz silt set in microcrystalline mosaic of calcite and mineral dolomite.

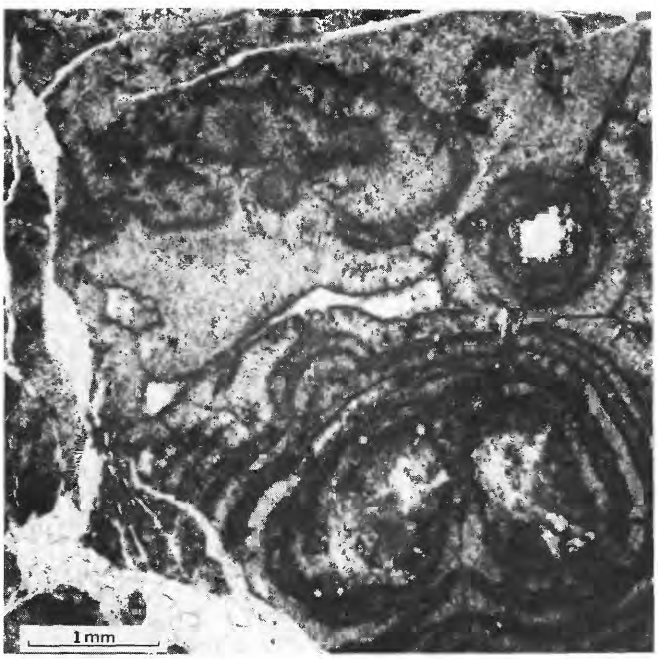

FIGURE 15.—Dolomite from buff dolomite member of Briggs Formation, south of Gypsum switch, Malone Mountains. Shows irregular banding within compound pisolitic bodies. Coarsely crystalline calcite fills interstices, forms veinlets, and locally occurs as aggregates near centers of pisolites.

set in a matrix of silty dolomite; elsewhere they are loosely cemented by secondary carbonate minerals.

The oolitic dolomite masses are interbedded with or gradational into crystalline white dolomitic limestone or stratified gray dolomite (fig. 16).

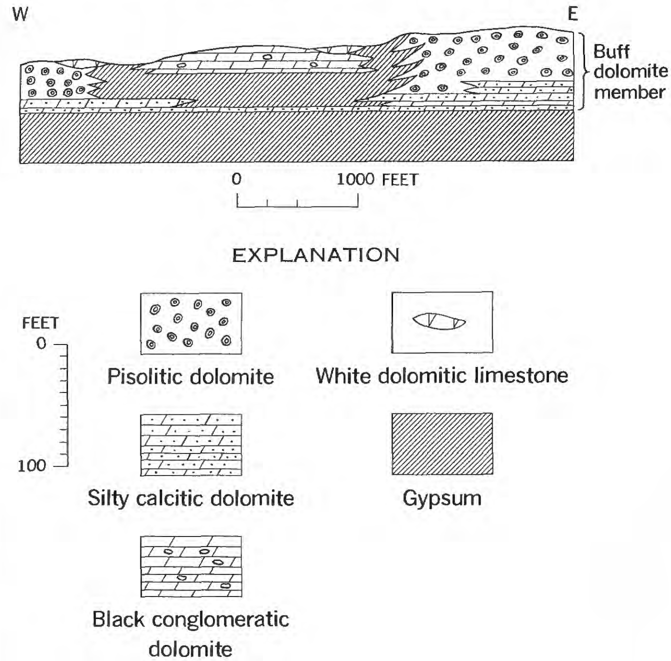

FIGURE 16.—Stratigraphic diagram showing relations between gypsum and carbonate rocks in the buff dolomite member of the Briggs Formation, northwest end of the Malone Mountains, directly south of Gypsum switch.

The carbonate rocks of the buff dolomite member have a wide range in composition (table 5), but the dolomitic limestones and calcitic dolomites are restricted in occurrence, the first to marginal parts of dolomite masses, and the second to the basal beds. The pisolitic rock is dolomite, although it may have the bulk composition of calcitic dolomite where it is veined or impregnated with secondary calcite.

FOSSILS

Fossils are abundant only in the black limestone member of the Briggs Formation, from which the following were collected and identified by Albritton (1938, p. 1756):

Productus ivesi Newberry
  occidentalis Newberry
  indicus Waagen
  leonardensis King
Marginifera reticulata King
Marginifera sp.
Avonia walcottiana var.
  costata King
Meekella? sp.
Dielasma? sp.
Hustedia? sp.
Pugnoides bidentatus Girty
Camarophoria venusta Girty
Ambocoelia guadalupensis Girty
Composita mexicana Hall
Pleurotomaria? sp.
Malonophyllum texanum Okulitch and Albritton

TABLE 5.—*Analyses of carbonate rocks from the buff dolomite member of the Briggs Formation*

[R. G. Guerrero, analyst (Guerrero and Kenner, 1955, table 3, p. 48)]

Specimen			Analyses (percent)				Remarks
No.	Classification	Locality	Acid insoluble	$CaCO_3$	$MgCO_3$	Nondetermined acid soluble, by difference	
A-11	Pisolitic(?) dolomite.	Hill, altitude 4,663 ft, Malone Mountains, Fort Quitman quadrangle.	0.37	59.13	40.95	None	Subspheroidal bodies, of which rock is largely made, are complexly intergrown, irregular in detail, and structureless except for scattered and randomly oriented tiny tubular bodies.
A-85	Pisolitic dolomite	South of Gypsum switch, Malone Mountains.	6.28	51.27	41.04	1.41	Single and compound pisolitic bodies with irregular concentric structure are set in dolomite showing spongy texture and abundant tiny tubular bodies.
A-86	Pisolitic dolomite with calcite veinlets.	do	.63	71.85	25.20	2.32	Calcitic dolomite by bulk composition. The calcite, however, occurs as veinlets and interstitial crusts, which are younger than remainder of rock.
A-7	Dolomitic limestone.	do	.52	90.93	8.37	.18	Original texture of rock not determinable. Thin sections show irregular wispy bodies of dolomitic rock set in mosaic of calcite crystals.
A-13	do	1.6 miles southwest of Torcer station, Malone Mountains.	.87	89.75	8.83	.55	As above, except that dolomitic rock shows contorted lamellar texture.
A-31	Silty calcitic dolomite.	1.8 miles S. 62° W. of Torcer station, Malone Mountains.	27.82	38.53	31.54	2.11	Insoluble residue is angular quartz silt.

The horn coral, *Malonophyllum texanum* Okulitch and Albritton, commonly weathers in relief and is the most conspicuous, but our collections indicate that the productid brachiopods are actually the most abundant and varied fossils.

The buff dolomite member exposed along the floor and side of Arroyo Balluco south of Gypsum switch has yielded unidentifiable specimens of rugose corals, algaloid accretions, and altered fossil fragments, probably of crinoid stems.

Thin sections indicate that most of the dolomitic rocks in the Briggs Formations contain structures possibly of algal origin. For example, the black dolomite member near the southeast end of the Malone Mountains contains aggregates of cryptocrystalline dolomite in filiform bodies 0.04 mm across in sinuously branching patterns traceable for 2 mm. Similar patterns occur in dark-gray dolomite interbedded with gypsum between the black and buff dolomite members; here the bodies are definitely tubular with dark walls 0.003 mm thick. These tubes occur singly, in parallel groups, or as entwined and irregular masses as much as 0.4 mm across. No transverse partitions were seen, but they otherwise resemble coarser tubes of the filamentous alga *Girvanella* in rocks of Permian age in the Guadalupe Mountains, about 60 miles northeast of the report area. (Johnson, 1942, p. 210–211).

Parts of the black dolomite member at the northwest end of the Malone Hills have a spongy structure (fig. 17) resembling that in a recent algal reef in Green Lake, N.Y. (Bradley, 1929, pl. 30*B*). The more finely crystalline bodies are about 0.25 mm wide, and the more coarsely crystalline interspaces about 0.10 mm.

At least some of the pisolitic bodies of the buff dolomite member may be of algal origin (fig. 18). The individual concentric layers are irregular, range from 0.02 to 0.23 mm in thickness, and follow no consistent pattern in spacing of thinner and thicker bands. Growth seems to have originated at one or more centers in each pisolite and to have been irregular from the beginning, as some layers grew only on one side. Some spheroidal or botryoidal masses lack concentric structure entirely but contain filamentous bodies like those already described.

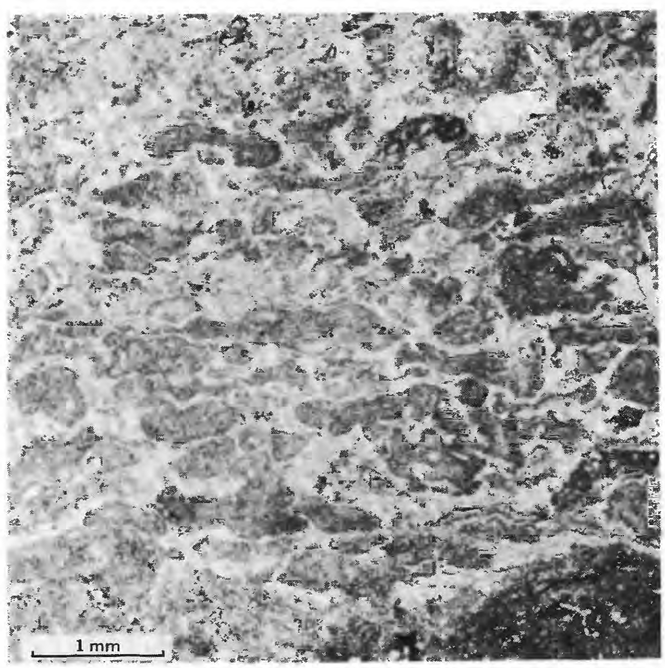

FIGURE 17.—Spongy structure in microcrystalline and cryptocrystalline dolomitic rock from the black dolomite member of the Briggs Formation, Malone Hills.

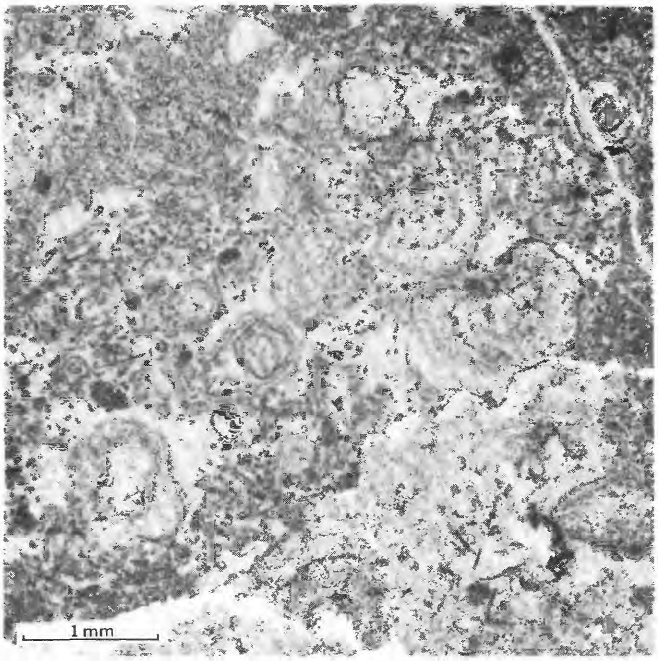

FIGURE 18.—Dolomite from buff dolomite member of Briggs Formation, south of Gypsum switch, in the Malone Mountains. Irregularly concentric structure of pisolitic masses in association with flexuous tubular bodies suggests that the rock originated as an algal limestone.

AGE AND CORRELATION

Albritton's list of brachiopods of the black limestone member indicates that this part of the Briggs Formation probably belongs to the Leonard Series. *Productus ivesi-Dictyoclostus bassi* and *Marginifera reticulata* are restricted to this series in western Texas (Branson, 1948, p. 332, 407). *Productus occidentalis-Dictyoclostus occidentalis* (in King, 1948, p. 22) is one of the two most abundant productids in the Bone Spring Limestone in the Guadalupe Mountains, although it also ranges into the Guadalupe Series. All the others likewise occur in the Leonard Series but are not restricted to it, except possibly *Avonia walcottiana* var. *costata*, which occurs in the Word Formation of the Glass Mountains.

The rugose corals in the buff dolomite member indicate merely that the uppermost part of the Briggs Formation is of Paleozoic age. According to Helen Duncan, much of the skeletal structure was obliterated by silicification and is too poorly preserved to indicate more than that the coral is one of the lophophyllids. The fact that this member unconformably underlies the Malone Formation and is conformable with the remainder of the Briggs suggests strongly that it is Permian, although whether it is of Leonard age or younger is undetermined.

RELATION BETWEEN PERMIAN ROCKS IN THE FINLAY AND MALONE MOUNTAINS AREAS

Rocks of Permian age in the Finlay and Malone Mountains cannot be related directly because they are separated by a belt of younger deposits. Two wells (fig. 52) drilled into these deposits passed through a thrust fault into rocks chiefly of Cretaceous age in the lower plate (see Cannon, 1940) and did not provide additional information. The Thaxton 1 well at Campo Grande Mountain penetrated beds of Permian age but did not yield enough information to be of use in interpreting the relation between the two areas. Figure 19 shows tentatively how the sequences in the two areas may fit together. In constructing this diagram two basic assumptions are made.

The first assumption is that the black limestone member of the Briggs Formation, which is the only thick limestone sequence in the Malone Mountains, is equivalent to units 8 through 13 (section 1) that make up the thickest dominantly limestone sequence in the Finlay Mountains. In both areas the fossils are of Leonard aspect, but we know of only one species of brachiopod (*Composita mexicana*) common to both sequences. Such variations in rocks and fossils as are implied by this correlation are no greater than are known elsewhere in the Permian System of Texas, although differences between the two sections reduce the probability that the correlation is correct.

The second assumption is that the pisolitic dolomite of the upper part of the Briggs Formation originated as an algal reef, which separated normally saline marine waters to the north from abnormally saline lagoonal waters to the south. To account for the stratigraphic range of the gypsum, which presumably accumulated in a back-reef area, the pisolitic bodies are shown extending downward to the upper layers of the black limestone member.

The variations in thickness and lithology within the Permian System of western Texas are generally considered to be related to a framework of basins and platforms. Sedimentary sections are typically thicker and of different lithology in the basins than on the platforms. Changes of facies are commonly localized along flexures that formed the boundaries between platforms and basins. The deposits of the Malone and Finlay Mountains have been interpreted (King, 1948, p. 25) as forming in the northwest end of the Marfa Basin near the border of the Diablo Platform (fig. 20). King drew the south border of the Diablo Platform through the Hudspeth County area approximately along the present border of the Diablo Plateau. According to this interpretation, the Finlay Moun-

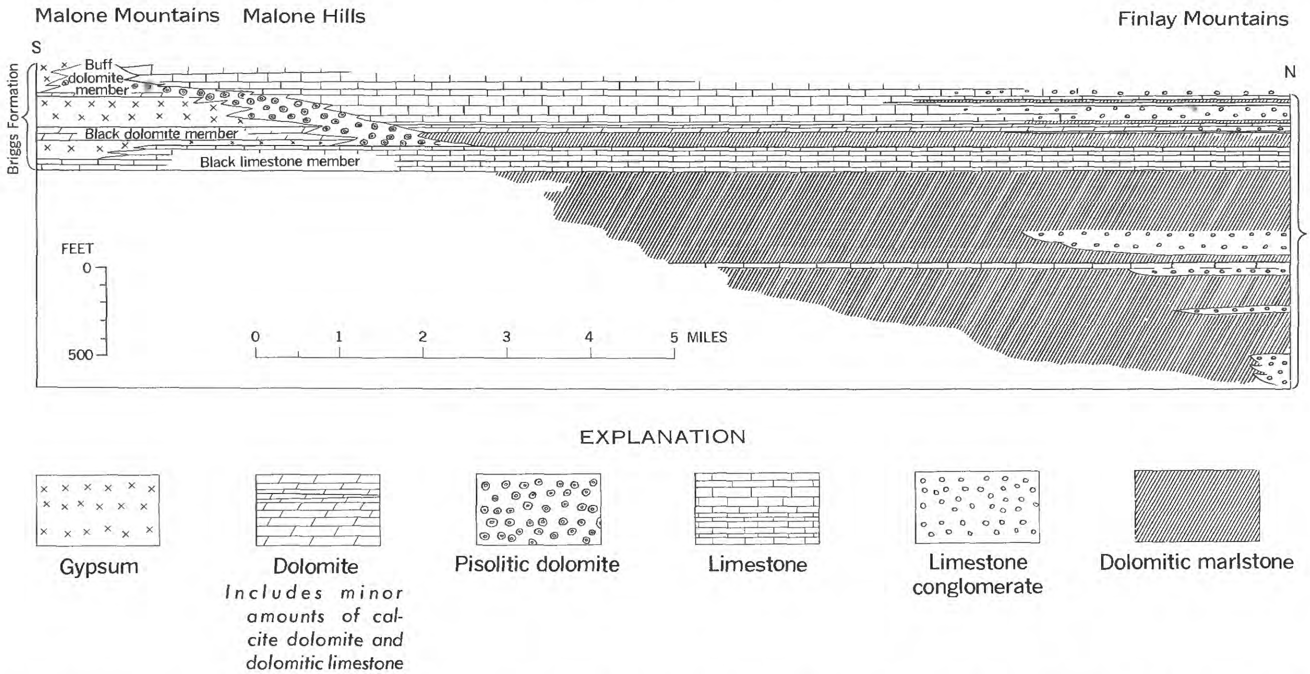

FIGURE 19.—Stratigraphic diagram showing possible original depositional relation between rocks of Permian age in the Malone and Finlay Mountains. The original distance between the sections exposed in these mountains is assumed to have been 15 miles, or about twice the present distance.

tains are in a zone of downward flexing along the south border of the platform.

The same patterns of contorted strata and gigantic crossbedding seen in the marlstone of the Finlay Mountains also show in parts of the Bone Spring Limestone of the Guadalupe Mountains. There, these distinctive primary structural features seem to be confined to a belt along the Bone Spring flexure, which is a monoclinal fold between the Delaware Basin and a shelf area to the northwest. (See fig. 20.) The channeling and subaqueous gliding may be due to the growth of the Bone Spring flexure during Leonard time (King, 1948, p. 15–27, pl. 11). By analogy, similar structural features in the Finlay Mountains might be cited as indirect evidence of a growing flexure along the south margin of the Diablo Platform.

If this assumption is true, the position of the Briggs Formation in the Malone Mountains is indeed anomalous. The formation would necessarily have been deposited south of the platform margin, but its evaporites and interbedded dolomitic rocks are more suggestive of accumulations on shelves than in basins. An explanation of this apparently anomalous position of the Briggs is that the Marfa Basin was narrow, as shown on figure 20, right, and that the exposed Briggs rocks were thrust northeastward from a shelf area. These displaced beds, thus, conceal part of the sedimentary rocks of the northwestern Marfa Basin, and the only exposed marginal autochthonous rocks are in the Finlay Mountains.

A thickness of 1,600 to 2,300 feet of Permian rocks does not, however, establish the former presence of a basin in southern Hudspeth County. Nor is there compelling structural evidence that the Malone section has been displaced more than a few miles from its original site of deposition. Assuming that the net displacement along concealed thrusts in the Malone Mountains area is equal to the combined displacements of the Devil Ridge and Red Hills thrusts, the original distance between the Malone and Finlay sections would be only about 15 miles, or twice the present distance (Smith, 1940, p. 630–632). Allowing an additional mile or so for shortening due to folding, the depositional site of the Malone section need have been only at about the present position of the Rio Grande.

If the southwest border of the Marfa Basin is placed roughly along the present course of the Rio Grande in the report area, the known local structural and stratigraphic requirements would be met, the Marfa Basin would be narrow in this area, and a southwestern shelf area probably would be beyond the Rio Grande.

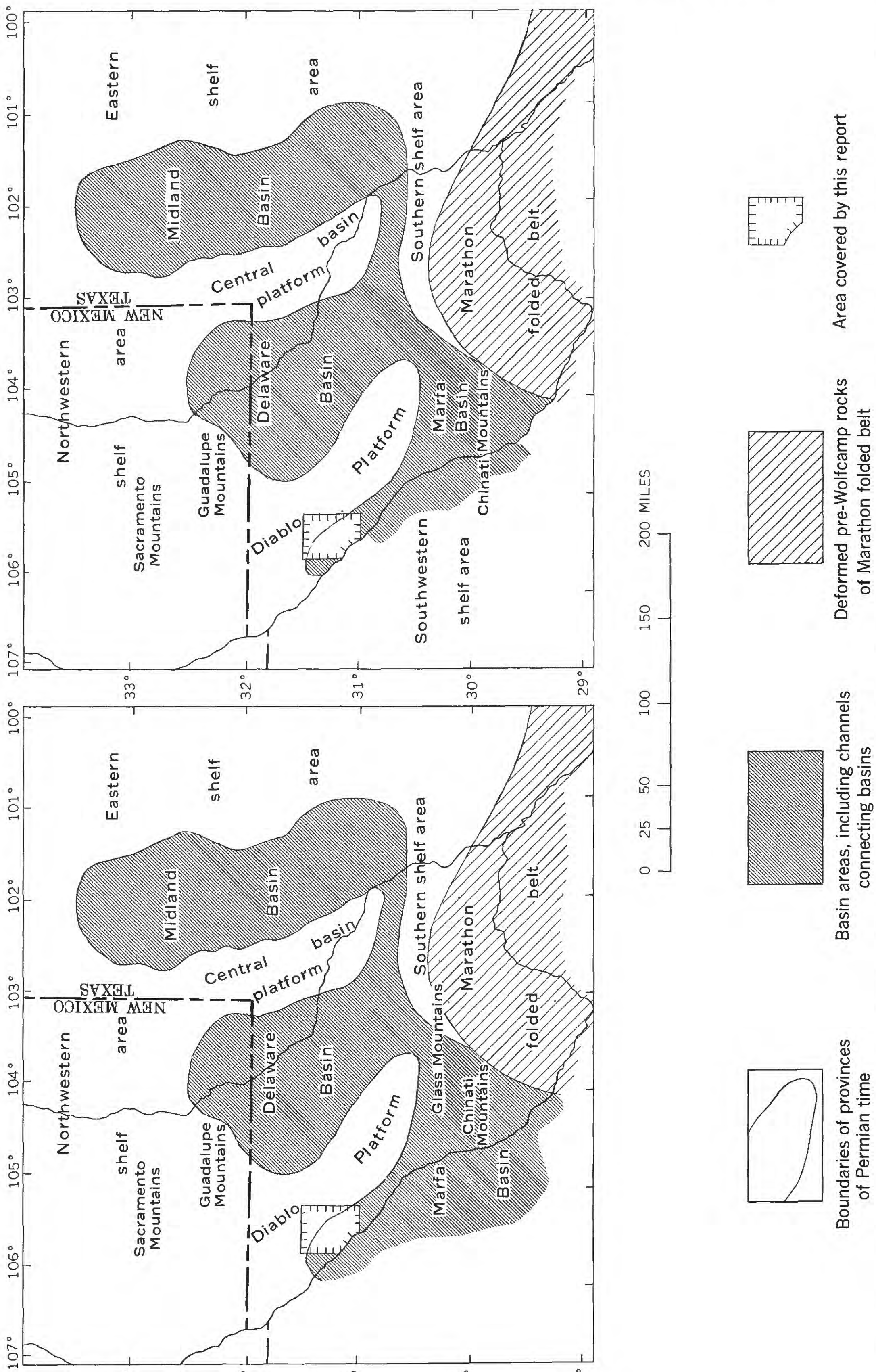

FIGURE 20.—Alternate interpretations of the extent of the Marfa Basin. Left: after P. B. King (1948, p. 25), showing relatively large basin. Right: modification of King's interpretation, showing relatively narrow basin arm extending into area covered by this report.

CONDITIONS OF DEPOSITION OF PERMIAN ROCKS

The Permian sediments accumulated on the floor of a sea that covered much of western Texas during Permian time. Contrasting sedimentary sequences in the Finlay and Malone Mountains indicate that environments were different in the two areas, although deposition probably was generally concurrent.

FINLAY MOUNTAINS

While the lower two-thirds of the sequence in the Finlay Mountains was being deposited, the waters that covered this area must frequently have been agitated and the sea floor swept by currents. At times colonies of bryozoans and communities of brachiopods populated the sea floor, but these populations were periodically buried by thin layers of lime-rich mud that preserved the skeletons. Occasionally, fronds and leaves of land plants drifted in from nearby shores and were buried with the shells. At intervals, currents moving in various directions scoured channels that were later filled by mud or gravel. Fusulinid tests and crinoid stem segments were transported with the limestone pebbles and incorporated in the gravel beds. Alternate scouring and filling produced many local unconformities, and the sediments were crossbedded on a grand scale. Foreset beds on banks of sediments occasionally crumpled and slumped to form lenses of contorted rock. Because the shifting and unstable bottoms on which the marlstone was deposited were unfavorable to life, this rock is mostly barren of fossils.

During deposition of the upper one-third of the sequence, conditions were more favorable to the growth of marine invertebrates. At times, mud and gravel were still spread over the bottoms; but at other times little clastic sediment was moved into the area, and shellfish grew in profusion and caused the formation of extensive deposits of organic limestone. Currents moved prevailingly eastward or westward and arranged some of the fusulinid tests in orderly rows, but these currents did not prevent many fragile bivalves from being buried intact.

MALONE MOUNTAINS

The oldest or black limestone member of the Briggs Formation was deposited as calcareous mud in marine waters under conditions that permitted a benthonic population of brachiopods and simple corals to flourish. Calcium sulfate was subsequently precipitated as anhydrite or gypsum because the salinity of the waters was increased probably by evaporation after the site of limestone deposition had been cut off from free communication with the sea. This change did not take place everywhere at the same time but apparently progressed northward from the southern part of the Malone Mountains, where the stratigraphic position of the black limestone member is occupied mostly by gypsum.

The alternation of dolomite and limestone with gypsum in the sequence above the black limestone member suggests that salinity of the waters fluctuated; so, the less soluble carbonates were precipitated at some times and the more soluble sulfates at others. Deposition of the black and buff dolomite members began with accumulation of clastic quartzose sediment during an influx of replenishing waters, but little detrital material was deposited in the upper parts of these members.

The black dolomite member probably originated mostly as a chemical precipitate, as it contains interbedded gypsum and fossils are sparse. The filamentous and spongy texture of parts of the dolomite may be of algal origin, but no extensive algal deposits have been recognized.

On the other hand, the pisolitic rocks of the buff dolomite member are probably algal reefs. They not only possess the spongy, filamentous, and pisolitic textures suggestive of algal growths but have the moundlike form of reefs. Corals perhaps contributed to the reef growth, but they are sparse, as are other marine invertebrates.

If algal mounds and ridges were built during deposition of the Briggs Formation, they may have been the barriers that shut off parts of the Permian seas and formed lagoons in which the gypsum was deposited by evaporation. The visible parts of the supposed reefs are high in the local stratigraphic section, but only a small part of the whole complex is exposed. This facies possibly extends down to the level of the oldest evaporites in the Briggs Formation in bordering areas where the formation is covered by younger rocks.

JURASSIC SYSTEM

MALONE FORMATION (RESTRICTED)

PREVIOUS USAGE AND DEFINITION

The name Malone has been variously used (fig. 9). Taff (1891) first applied the name Malone Bed to what is now called the Briggs Formation and, relying on the meager paleontological evidence then available, assigned the formation to the "Washita division" of the Cretaceous. Cragin (1905) described a large Jurassic fauna from strata overlying Taff's Malone Bed and used the name for all the rocks of the Malone Mountains area; thus, he implied a Jurassic age for all these beds. Baker (1927, p. 11), however, discovered Permian fossils in what we now call the black limestone member of the Briggs Formation and therefore restricted the name Malone to the overlying beds of Mesozoic age. Adkins (1932, p. 286–291) excluded the upper several hundred feet of these beds because they contain Early Cretaceous rather than Jurassic fossils. Albritton (1938, p. 1758, 1764) also restricted the name Malone to the beds of known Jurassic age. The Malone Formation as thus defined is bounded below by the unconformity at the top of the Briggs Formation and above by a quartzitic sandstone and siliceous conglomerate that is perhaps the most distinctive and conspicuous stratigraphic unit in the Malone Mountains.

GENERAL FEATURES

The Malone Formation is a mixture of many different kinds of rock complexly interbedded. It is broadly divisible into lower and upper members, the lower being mostly sandy shale, siltstone, sandstone, and conglomerate, and the upper, predominantly limestone. At all localities the contact between them is well marked and conformable; but this contact is transitional, and because it transgresses time lines irregularly, parts of the two members are of the same age.

The Malone Formation thins southeastward along the trend of the Malone Mountains. It is 850 to 1,000 feet thick in the northwestern part of the mountains but no more than 390 feet thick at the southeast end; three-quarters of a mile farther southeast, it is only 190 feet thick. At the observed rate of thinning, the formation probably wedges out at some place along the northwest front of the Quitman Mountains, although it is not exposed there (Huffington, 1943, p. 995).

The formation also thins and disappears north of the Malone Mountains. In the Malone Hills, about 2 miles northeast of the Malone Mountains, the upper member has been thinned by erosion, and only 210 feet of the formation is exposed. The Malone is absent from the Finlay Mountains, where Cretaceous rocks lie on Permian rocks.

REFERENCE SECTION

The reference section of the Malone Formation is designated herewith as sections 14 and 15 of Albritton (1938, p. 1773–1801). As shown on plate 2, one of these sections crosses the lower member; the other, the upper. The two sections overlap and are here combined as one. This section is more complete, is better exposed, contains more fossils than most sections, and well displays the diverse lithology of the lower member.

SECTION 14.—*Reference section of the Malone Formation (restricted)*

[Combining sections 14 and 15 of Albritton (1938, p. 1787–1790) with minor modifications. At hill 4494, 2½ miles northwest of Hilltop Cafe, and the ridge slope on the northeast side of hill 5016, 2¾ miles north-northwest of Hilltop Cafe; traverse 14 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

	Thickness (feet)
Lower Cretaceous(?)—Torcer Formation:	
69. Sandstone, rusty, quartzitic, and chert pebble conglomerate; top not exposed	23
68. Sandstone, gray, shaly; contains lenses of well-rounded chert pebbles	14
67. Sandstone, gray, calcareous; contains *Exogyra* aff. *E. potosina* and fragments of ammonites	5
66. Sandstone, buff- to brown-weathering, quartzitic; contains interbeds of more calcareous, less indurated sandstone in beds as much as 2.5 ft thick; contains *Saccammina* cf. *sphaerica*, *Lagena*? sp., *Gümbelina pauci-striata* and *Anomalina torcerensis*	17
65. Limestone, black to gray, arenaceous, grading upward into calcareous sandstone; contains *Exogyra* sp. and *Pleuromya* sp	3
Total exposed thickness	62
Upper Jurassic—Malone Formation, upper member:	
64. Limestone, gray to black, gray-weathering; generally arenaceous, particularly at base where rock grades imperceptibly into calcareous sandstone; beds are 6 in. to 5 ft thick	327
Upper Jurassic—Malone Formation, lower member:	
63. Sandstone, gray, brown-weathering, ferruginous and calcareous, in beds as much as a foot thick, containing scattered pebbles and lentils of chert pebble conglomerate; locally crossbedded	12–15
62. Sandstone, thin-bedded, gray, brown-weathering; contains interbedded black, arenaceous limestone	31
61. Limestone, black, gray- and brown-weathering, arenaceous	1.5
60. Shale, gray, brown-weathering, sandy	4
59. Limestone, black, gray- and brown-weathering, arenaceous	1.5
58. Shale, gray, brown-weathering, sandy	27
57. Limestone, black, arenaceous; contains *Serpula* sp., *Gryphaea mexicana*, *Nerinea goodellii*, *Pholadomya* sp., *Lithacoceras*? *malonianum*, and echinoid fragments	8
56. Sandstone, gray, calcareous, weakly indurated	21
55. Sandstone, gray, calcareous, and arenaceous limestone, contains abundant *Gryphaea mexicana*	1
54. Sand, gray, calcareous	2
53. Limestone, black, coquinoid, arenaceous; contains abundant *Gryphaea mexicana*	4
52. Sand, dark-gray- to tan-weathering	26
51. Sandstone, gray, brown-weathering, calcareous	0.5
50. Sand, dark-gray- to tan-weathering	2
49. Sandstone, gray, brown-weathering, calcareous	0.5
48. Sand, dark-gray- to tan-weathering	1
47. Sandstone, gray, calcareous, weakly indurated, weathering brown	1

SECTION 14.—*Reference section of the Malone Formation (restricted)*—Continued.

Upper Jurassic—Malone Formation, lower member—Continued	*Thickness (feet)*
46. Sand, dark-gray- to tan-weathering	4.5
45. Sandstone, weakly indurated, brown-weathering, calcareous	1
44. Sand, gray- to tan-weathering	13
43. Sandstone, weakly indurated, gray, brown-weathering, calcareous; contains *Lucina potosina, Entolium* sp., and ammonite fragments	1
42. Sand, buff	13
41. Limestone, black, arenaceous; contains *Nerinella stantoni* (unusually abundant), *Gryphaea mexicana, Lima riograndensis, Haploceras cragini, Idoceras schucherti, I. clarki, Lithacoceras? malonianum, Physodoceras smithi, P. booni, Aspidoceras laevigatum, Nebrodites nodosocostatus,* and *Serpula* sp	14
40. Sandstone, thin-bedded, buff, interbedded with arenaceous limestone and calcareous sandstone containing *Gryphaea mexicana, Pinna quadrifrons,* and *Entolium* sp	27
39. Limestone, pebbly, black, arenaceous; contains abundant *Gryphaea mexicana* and ammonite fragments	2.5
38. Sandstone, weakly indurated, buff- and brown-weathering, shaly; locally well cemented where more calcareous	21
37. Conglomerate of limestone pebbles and cobbles, tan-weathering; contains sandy matrix; grades eastward into calcareous sandstone	0–6
36. Shale and limestone in alternating beds, sandy, gray-weathering, thin-bedded throughout	20
35. Sandstone, gypsiferous, tan and light-gray and interbedded reworked granular gypsum	57
34. Conglomerate of limestone pebbles and cobbles grading westward into gypsum and sandstone	0–3.5
33. Sandstone, gypsiferous, interbedded with reworked granular gypsum	32
32. Sandstone, gray, calcareous, and granule conglomerate; contains lentils of coarser conglomerate having pebbles as much as 3 in. in diameter	3.5
31. Conglomerate of limestone pebbles	4
30. Sandstone, hard, gray, calcareous; contains abundant shell fragments; divided by bed of gray shaly sand about 1.5 ft thick	7
29. Unexposed	3
28. Sandstone, gray, calcareous; contains shell fragments	2
27. Sand, gray, fine-grained	10
26. Sandstone, gray, calcareous, and arenaceous limestone	2.5
25. Shale, powdery, sandy, weathering buff	7
24. Conglomerate of limestone pebbles and cobbles	2.5
23. Sandstone, gray, calcareous, grading westward into limestone pebble and cobble conglomerate	2.5
22. Shale, buff- and purple-weathering, arenaceous; shaly sand and interbedded gray calcareous sand	14
21. Conglomerate of limestone pebbles, gray-weathering, grading upward into gray, calcareous and arenaceous limestone; contains abundant *Astrocoenia* and *Serpula* spp	3.5
20. Sandstone, lamellar, gray, calcareous, weathering brown	4
19. Shale, sandy, powdery, buff and purple	12
18. Sandstone, thin-bedded, gray, calcareous, interbedded purple sandy shale	14
17. Shale, buff and purple, sandy	9
16. Limestone, dense, black, sandy	1
15. Shale, sandy, buff- and purple-weathering	6
14. Limestone, sandy, dense, black	1
13. Shale, sandy, buff- and purple-weathering	8.5
12. Limestone, laminated, gray, arenaceous; and calcareous sandstone	2
11. Shale, powdery, gray, buff to purple-weathering; poorly exposed	34
10. Limestone, black, arenaceous; contains large *Lucina* and fragments of petrified wood	1–3
9. Shale, sandy, powdery, purple-weathering; poorly exposed	4
8. Limestone, black, arenaceous	1
7. Sandstone, gray, calcareous; weathers brown	2
6. Shale, powdery, gypsiferous, sandy, weathers purple	9
5. Sandstone, gray, calcareous; weathers brown	2
4. Sandstone, buff-weathering; poorly exposed	27
3. Gravel, limestone granule	2
2. Unexposed	10
Total thickness of lower member of Malone Formation	561

Unconformity.

Permian—Briggs Formation:

1. Dolomite, dark-gray, pisolitic; obscurely bedded to massive.

LOWER MEMBER

The stratigraphic diagram on figure 21 shows the variety and complex pattern of the different sedimentary facies in the lower member; the diagram is generalized, and in places the true complexity is greater than shown. Although the member is a mixture of many kinds of rock in interfingering bodies, it shows the following general features:

1. The rocks are predominantly clastic. Quartz sand and silt are scattered through the limestones, shales, and limestone conglomerates and also form beds of sandstone and siltstone.
2. The rocks are calcareous. Calcite is the commonest cement of the sandstones and siltstones and is present in most of the shales also.
3. The rocks are thin bedded and are in thin lithic units. More than half of the 570 lithic units listed in the detailed sections of Albritton (1938, p. 1773–

761-386 O—65——3

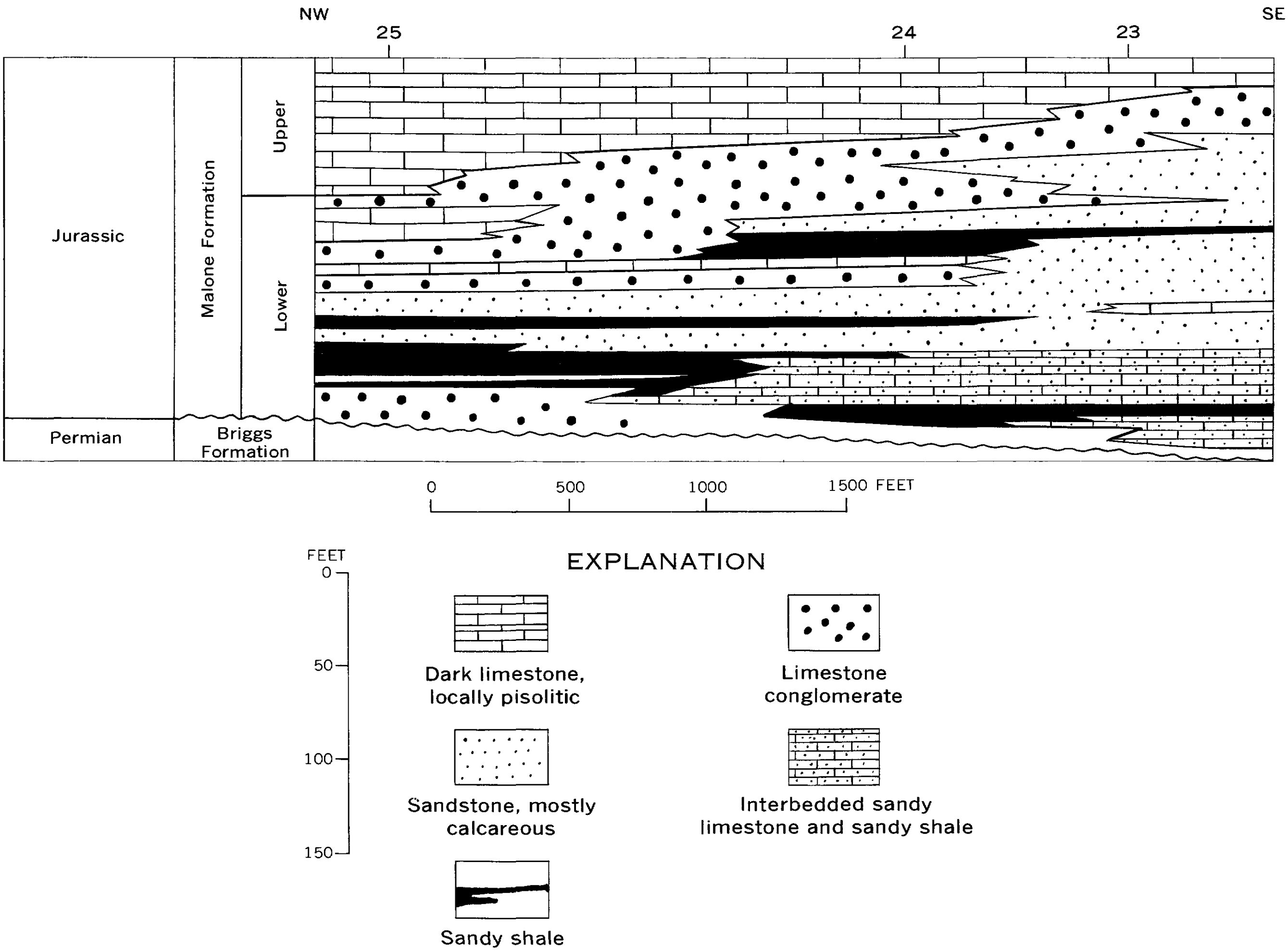

FIGURE 21.—Stratigraphic diagram of Malone Formation, southeast end of Malone Hills. Shows diverse lithology of lower member and interfingering relations between lower and upper members. (Based largely on stratigraphic sections 23, 24, and 25 of Albritton, 1938, p. 1797–1801.)

1801) are 5 feet thick or less, and more than three-fourths are 10 feet or less.

4. Changes of facies are common in single beds. Within a few score feet, conglomerate may grade into sandstone or pebbly limestone, and siltstone into silty shale. Limestone beds can be traced for greater distances than the other kinds of rock.
5. The limestones and some of the more calcareous sandstones contain abundant and varied fossils, and many other beds are sparsely fossiliferous.

In most places from a fifth to a half of the lower member consists of sandstone. The sandstone is gray or brown, finely laminated or cross laminated, and ranges from very fine grained to very coarse grained, the fine grading into siltstone and the coarse into conglomerate. Variation in texture is the rule, so that most individual beds of sandstone ordinarily lose their identity within a few hundred yards along the strike. In thin section the quartz grains are mostly angular to subrounded. Even the very fine grained sandstone contains grains of limestone or chert, which are mostly about the same size as the quartz, but generally rounder; they are nearly as abundant as the quartz in the coarser sandstones. The cementing material is calcite, which appears in thin section as microcrystalline mosaics. In places, calcite crystals entirely fill the spaces between the grains and make a firmly indurated rock. In other places, calcite crystals only partly fill the voids, and although many of the quartz grains then have secondary overgrowths, the rock is weakly indurated.

By decrease in grain size the sandstones pass into siltstones and, with addition of clay, into sandy and silty shale. These fine-grained rocks are pinkish and reddish brown to very dark gray. They account for about half the section at the northwest end of the Malone Mountains near Gypsum switch but decrease toward the southeast and make up only about 5 percent of the section near the southeast end of the mountains; in the Malone Hills they are only minor constituents of the lower member.

In a few places siltstone forms layers more than 15 feet thick. The siltstone is massive and has irregular fracture. Arenaceous shale, on the other hand, splits roughly parallel to the bedding. In thin section, the quartz appears as angular grains in a cryptocrystalline matrix of carbonate and clay minerals. Shell fragments are scarce, and fossils are generally uncommon.

Conglomerate occurs at various horizons from the bottom to the top of the member. Conglomerate bodies range in size from lentils no thicker than the diameters of the pebbles to at least 35 feet thick, and some poorly exposed bodies in the southeastern part of the Malone Mountains may even be 100 feet thick. Some of the smaller bodies fill channels and so presumably have elongate shapes. Most bodies are broadly lenticular or tabular but highly irregular in detail. In most places a coarse boulder conglomerate marks the base of the Malone Formation (fig. 22); this conglomerate is coarser than those higher in the formation.

The conglomerate layers rest on sharply defined undulatory surfaces that cut across the underlying beds (fig. 23). Most of these surfaces are minor disconformities evidently produced by the scouring action of currents, but none appears to persist laterally beyond the limits of the conglomerate with which it is associated.

The conglomerate fragments range in diameter from one-eighth inch to 2 feet but are mostly pebbles and cobbles 1.5 to 3 inches in maximum length; sorting is generally poor. Most of these fragments are subrounded to rounded and ellipsoidal, and the two longer axes are approximately in the plane of the bedding. The longer axes are roughly alined in limited areas; in some beds at the northwest end of the Malone Hills the pebbles and cobbles are also imbricated. The matrix of the conglomerates is mostly calcareous sandstone. In many places conglomerate grades upward or laterally into pebbly sandstone, which in turn passes into sandstone without pebbles.

The fragments in the conglomerate are mostly limestone and dolomite and near the base of the formation are obviously derived from local sources. In the Malone Hills the conglomerate includes boulders that came from the black limestone member of the Briggs Formation, as identified by corals and brachiopods in them. Near Gypsum switch the conglomerate lies on the buff member of the Briggs and contains boulders derived from the basal silty dolomite of that member. In the southeastern Malone Mountains, blocks of the

FIGURE 22.—Coarse basal conglomerate of Malone Formation, near southeast end of the Malone Mountains. The scale is 6 inches long.

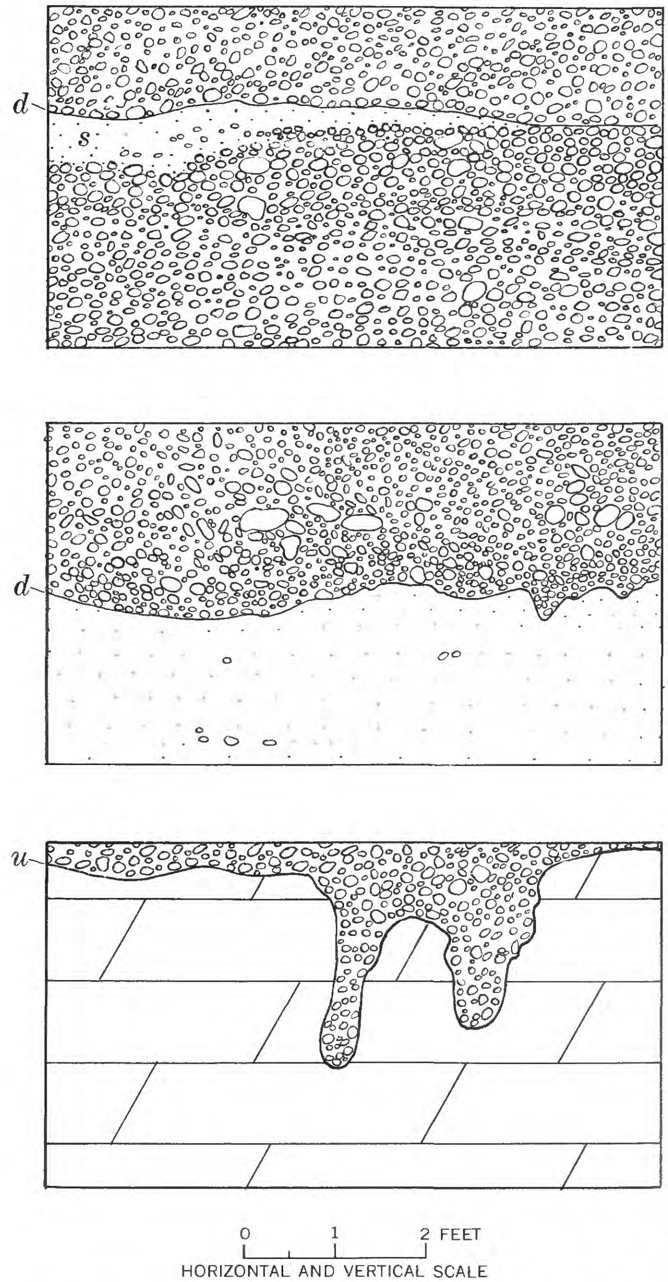

FIGURE 23.—Primary structures associated with conglomerate in the lower member of the Malone Formation. Top: conglomerate grading upward and laterally into sandstone (*s*) below a local disconformity (*d*). Middle: conglomerate filling channels in sandstone along disconformity (*d*). Bottom: detail along unconformity (*u*) between Briggs and Malone Formations; basal conglomerate of the Malone fills channels in dolomite of the Briggs (locality 2 miles S. 30° W. of Torcer station).

distinctive breccia in the black dolomite member of the Briggs abound in the basal conglomerate of the Malone. Conglomerates near the top of the lower member do not contain these native rocks and evidently were derived from more distant sources. They were not reworked from conglomerates in the Leonard Series of the Finlay Mountains, for the fragments in the conglomerate of Permian age are generally not as coarse as those of the Jurassic.

Chert fragments are persistent but minor components of the conglomerates. Those fragments in the basal conglomerates almost certainly came from the Briggs Formation, but those higher in the section may have come from outside the Malone Mountains area.

The conglomerates are in general poorly fossiliferous, and many contain no fossils. Some, however, do contain petrified wood, and in a few of these, the wood is accompanied by marine invertebrate shells.

At most places limestone makes up 5 to 20 percent of the lower member, but near the southeast end of the Malone Mountains it accounts for half or slightly more of the member. Limestone everywhere forms thin units interbedded with the other rocks. Most of the beds are no more than a foot thick, and in only a few places do they form sets as thick as 10 or 15 feet. There are four varieties of the limestone.

The most common type of limestone is dark gray and is formed of quartz grains mixed with fragments of pelecypod and gastropod shells, bound together in a matrix of microcrystalline calcite (fig. 24). The shells have lost their original lamellar or prismatic structure. Larger shell fragments have been reconstituted to mesocrystalline mosaics of calcite, and these in turn have changed to microcrystalline aggre-

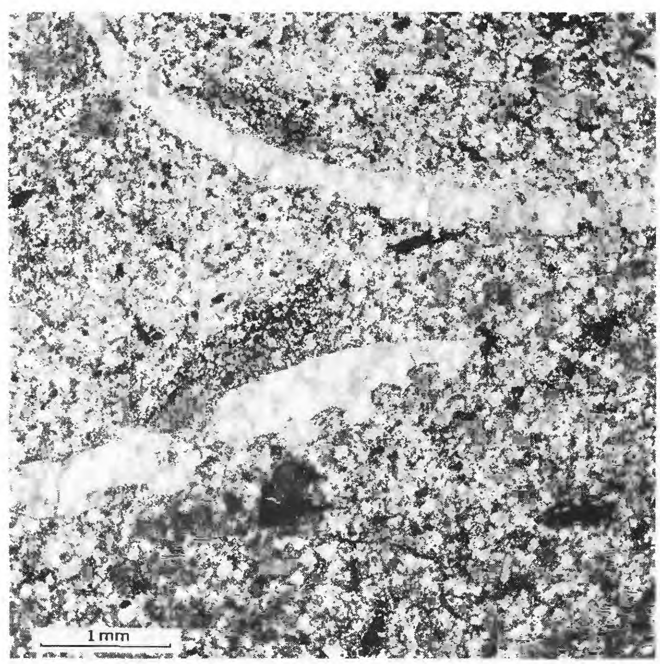

FIGURE 24.—Fossiliferous sandy limestone from lower member of Malone Formation, Malone Hills. Small white spots are quartz in very fine angular grains set in microcrystalline calcite. Shapes of pelecypod shells are preserved in calcite, reconstituted as crystalline mosaics. Irregularities along borders of shells are the result of further recrystallization of calcite to form fine-textured mosaics, which are all but indistinguishable from the cement.

gates along parts of their surfaces, which appear roughened and corroded. Some of the smaller fragments have changed entirely into a finer textured material, which would be indistinguishable from the matrix were it not that these ghosts of shells contain no sand grains. This type of limestone probably originated as clastic shelly sand and sandy coquina; many of the layers blend with sandstone.

A second variety of limestone is dark gray, finely crystalline, and virtually free of quartz. It forms beds a foot or less thick made up of intergrown spheroidal septarian bodies, each as thick as the bed itself. This variety is common in the lower part of the member around Gypsum switch but nowhere accounts for more than a small fraction of the total section. Small scallop shells which occur in some of the beds are well preserved and retain their original nacreous luster. Beds of this kind are probably intergrown concretionary masses that developed in limy mud during or shortly after deposition.

A third variety is clearly of organic origin and is formed of closely packed whole shells and fragments of pelecypods, notably of the oyster *Gryphaea.* These beds exceed a foot in thickness in a few places; they occur sporadically throughout the member but do not persist laterally for more than a few score feet. Most were probably small oyster reefs that were buried beneath sediment before they had spread over any considerable part of the sea floor.

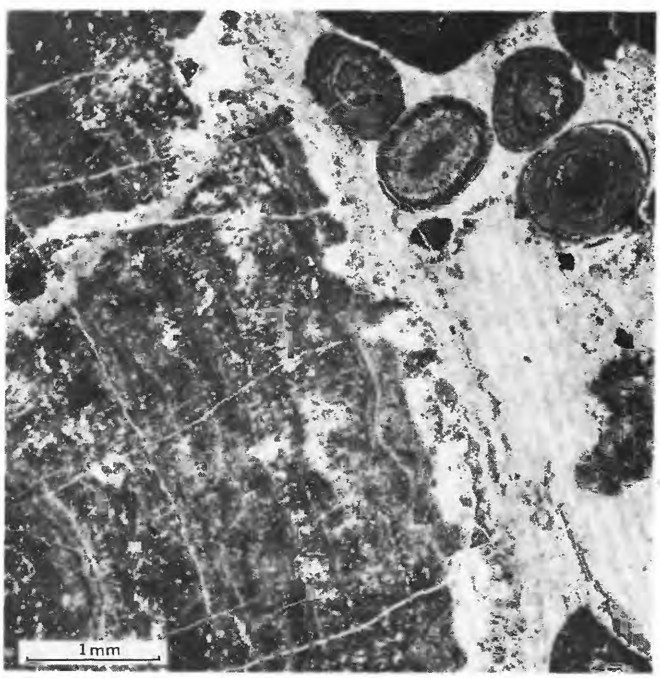

FIGURE 25.—Limestone made of algal pebbles and oolites, lower member of Malone Formation, Malone Hills. Part of an algal pebble shows at left. Some of the oolites have algal growths at centers. Microcrystalline calcite forms the cement. Similar rocks occur in upper member of Malone Formation.

Finally, some limestone beds in the upper part of the lower member in the Malone Hills are made of algal pebbles (fig. 25). Whereas rocks of this type are uncommon in the lower member, they are fairly abundant in the upper member.

In places in the central and northwest Malone Mountains, the basal and middle parts of the lower member contain gypsum in the form of light-gray granular selenite interbedded with mixtures of selenite and quartz sand and, locally, with lentils of limestone conglomerate. Approximately 17 percent of the reference section is gypsiferous. Except for some powdery gypsiferous and sandy shale near the bottom of the member, the gypsum is concentrated in an interval 90 feet thick near the middle. A mile and a half north of the reference section, 88 feet of evenly bedded sandy gypsum and gypsiferous sandstone, in layers about 3 inches thick, lies at the same stratigraphic level (Albritton, 1938, p. 1782).

The gypsum is lacking in the southeastern Malone Mountains and outlying hills and in the Malone Hills. The gypsiferous rocks are evidently discontinuous bodies that grade laterally into siltstone and sandstone.

UPPER MEMBER

The upper part of the Malone Formation consists mostly of gray fine-textured limestone in 3- to 7-foot beds. Analyses of four samples are given in table 6.

TABLE 6.—*Analyses of limestone from the upper member of the Malone Formation*

[R. G. Guerrero (1952), analyst]

Locality	Analyses (percent)			
	Acid insoluble	$CaCO_3$	$MgCO_3$	Total
Southeast end of Malone Mountains	0.21	97.69	0.56	98.46
Hill 2 miles southeast of Torcer station	.55	97.78	.86	99.19
South end of Malone Hills, 1.4 miles southeast of Torcer station	2.82	95.55	.61	98.98
Do	2.26	95.87	.63	98.76

Much of the limestone is made of algal growths. In some beds the algae form spheroidal heads, which give the rock a pebbly texture, but in most of the beds the growths are not visible on the outcrop so that the rock has an evenly fine textured appearance. Without thin-section study, such rocks would appear nonfossiliferous, yet they are biogenic throughout.

The algal heads in the pebbly beds are as much as 12.5 cm across, each head being made of alternating fibrous and crustiform layers of cryptocrystalline calcite, concentrically arranged. In the fibrous layers the filaments are about 0.05 mm in diameter and radiate from the centers of the pebbles; crustiform layers are concentrically laminated. The internal structure is identical with the structure of recent and fossil algal heads elsewhere (Bradley, 1929, pls. 30 and 34). Mixed with the algal pebbles are spheroidal oolites 0.05 to 0.70 mm in diameter. All the oolites are concentrically banded, and some have nuclei of algal limestone particles.

STRATIGRAPHIC RELATIONS WITH THE BRIGGS FORMATION

The Malone Formation lies on the Briggs Formation with angular unconformity. In single exposures this unconformity is not impressive, for the angular discordance is only a few degrees and has been obscured by later folding. The unconformity, however, is clear from relations over a wider area.

In the greater part of the Malone Mountains, the Malone Formation rests with uneven contact on various units of the buff dolomite member of the Briggs Formation. Near the southeast end of the mountains, however, the contact cuts across the buff member as well as the gypsum below it; therefore, the Malone here rests on the black dolomite member, as it does also at the northwest end of the Malone Hills. Altogether, the unconformity at the base of the Malone has stratigraphic relief of at least 450 feet.

The depositional character of the contact is best indicated by V-shaped channels that extend down several feet into the Briggs Formation and have their acute terminations pointing toward the Briggs (fig. 23). These channels are filled with conglomerate that grades up into higher beds of the Malone. Basal beds of the Malone commonly contain rounded cobbles and boulders derived from underlying limestone or dolomite of the Briggs.

FOSSILS

Invertebrate fossils are irregularly distributed throughout the Malone Formation but are most abundant in the lower member. In this member, the fossils are chiefly in thin beds of impure limestone, but they occur sparsely in all rocks except gypsum. Pelecypods and gastropods predominate; worms, corals, ammonites, and nautiloids are less common; and foraminifers, bryozoans, brachiopods, and echinoids appear to be relatively scarce. At a few localities, notably at the south end of the Malone Hills, invertebrate fossils weather free, but the shells are mostly tightly cemented in the matrix. The fossils are chiefly in coarsely crystalline calcite, which ordinarily does not preserve the original internal structure. Fragments and logs of petrified wood are scattered through the lower 100 feet of the formation and in places occur in the same beds with the marine invertebrates. The silicified wood weathers from the rock and lies free on the surface.

FORAMINIFERA

Although many samples from the silty shale, siltstone, and loosely indurated sandstone of the Malone Formation have been washed, only a few specimens of Foraminifera have been found. These belong to two species of *Robulus*, both of which closely resemble species in the Late Jurassic rocks of Europe (Albritton, 1937a, p. 20–21).

CORALS

Massive spheroidal coral heads as much as 6 inches across occur in the lower member and have been identified as *Astrocoenia maloniana* (T. W. Vaughan, in Cragin, 1905, p. 34–35). At the type locality of this species in the southern Malone Hills, these heads occur in varicolored siltstone and calcareous sandstone 60 to 80 feet above the base of the formation. In the Malone Mountains they are common in shelly limestone, arenaceous limestone, and calcareous sandstone from 400 to 750 feet below the top of the formation.

In places, several coral heads occur together in the same stratum, invariably associated with other fossils, and appear to have been buried in position of growth. At the lower limit of their range in the Malone Mountains, coral heads are associated with abundant masses of calcareous worm tubes, but higher up they are more commonly associated with a variety of pelecypods and, in the Malone Hills, with gastropods as well. The corals and mollusks form thin biostromal layers in places, but nowhere do they seem to have built reefs.

BRYOZOANS

Cragin (1905, p. 38) described colonies of the bryozoan *Berenicea maloniana* Cragin incrusting a gastropod shell in the Malone Hills, but bryozoans were not found later, and they are probably uncommon. The general absence of incrusting organisms on marine shells in the Malone Formation suggests that the shifting and current-swept sandy bottoms were unfavorable to growth of bryozoans.

BRACHIOPODS

In places in the lower member terebratulids occur with the pelecypods *Astarte* and *Gryphaea;* south of Gypsum switch, fragmentary specimens half an inch to an inch long are fairly common throughout an interval between 330 and 360 feet above the base of the formation. Elsewhere, brachiopods are scarce in the Malone Formation.

GASTROPODS

Cragin (1905, p. 88–100) described 18 species of gastropods from the Malone Formation, of which 7 were based on single specimens. They include the low-spired *Nerita nodilirata* Cragin and *Natica williamsi* Cragin, which is most abundant, and the high-spired *Pseudomelania goodellii* Cragin. Very long and thin nerineids are also common at some horizons, though mostly as fragments.

Gastropods occur in the same beds with pelecypods and other marine invertebrates. In the Malone Mountains they are most abundant at horizons between 350 and 700 feet below the top of the formation, where they are associated with the tube-building worm *Serpula*, the sedentary pelecypod *Gryphaea*, or both, though not to the exclusion of other kinds of fossils.

CEPHALOPODS

Cragin (1905, p. 100–101) described two nautiloids: *Nautilus burkarti* Castillo and Aguilera and *N. naufragus* Cragin, both from the lower member of the Malone Formation. Neither is abundant.

Ammonites are more abundant and varied. Albritton (1937b) identified 12 species, all but two of which are in the lower member. Sculptured shells include *Nebrodites nodosocostatus* Burckhardt, *Kossmatia zacatecana* Burckhardt, *K. aguilerae* (Cragin), *Lithacoceras? shuleri Albritton*,[3] L.? *malonianum* (Cragin), *Aspidoceras* cf. *laevigatum* Burckhardt, *Physodoceras booni* Albritton, *P. bakeri* Albritton, and *P. smithi* Albritton. *Haploceras cragini* Albritton, *Idoceras schucherti* (Cragin) and *I. clarki* (Cragin) are compressed shells that have little or no ornamentation on the mature portions.

In the Malone Mountains along the line of section shown in plate 2, *Idoceras* and *Haploceras* dominate in the lower member between 460 and 670 feet below the top of the formation. A few sculptured shell species also occur in this zone, but no ammonites of any kind were found beneath it. Above this zone all ammonites found were of the sculptured kind. In the Malone Hills we found only *Haploceras* and *Idoceras*, but Cragin previously reported *Lithacoceras? malonianum* and *Physodoceras smithi* from this locality.

PELECYPODS

About 60 species or varieties of pelecypods are reported from the Malone Formation (Albritton, 1938, p. 1761–1762; Stoyanow, 1949, p. 70–77); about half of these occur in both members of the formation and half occur only in the lower member; only one—*Exogyra potosina* Castillo and Aguilera—is restricted to the upper member.

Table 7 shows the stratigraphic occurrence and geographic distribution of the pelecypods, based on data from Cragin (1905), Albritton (1938, p. 1773–1801), and our field observations.

Many of the pelecypod species are rare, as demonstrated by the fact that few specimens have been found over a span of several decades, although a number of

TABLE 7.—*Stratigraphic occurrence and geographic distribution of pelecypods in Malone Formation in Malone Mountains*

Superfamily	Species	Lower member		Upper member	
		Localities	Units	Localities	Units
Nuculacea	*Nuculana? navicula* Cragin	1	1	0	0
Arcacea	*Cucullaea? texticostata* Cragin	1	1	0	0
	transpecosensis Cragin	1	1	0	0
	catorcensis Castillo and Aguilera.	2	2	0	0
	castilloi Cragin	2	2	0	0
	Arca taffii Cragin	2	2	0	0
	Arca? dumbli Cragin	3	3	0	0
Pteriacea	*Pinna quadrifrons* Cragin	9	15	1	1
	Gervillia corrugata Cragin	1	2(?)	1	1
	cinderella Cragin	1	1	1	1
	Gervillia? riograndensis Cragin	1	1	1	1
Ostracea	*Gryphaea mexicana* Felix	14	47	1	1
	Exogyra subplicifera Felix	2	2	0	0
	potosina Castillo and Aguilera	0	0	2	2
Trigoniacea	*Trigonia vyschetzkii* Cragin [1]	6	13	0	0
	goodellii Cragin	3	4	0	0
	calderoni Castillo and Aguilera.	2	2	0	0
	proscabra Cragin	3	7	0	0
	praestriata Cragin	2	2	1(?)	1(?)
	munita Cragin	4	4	0	0
	rudicostata Cragin	1	1(?)	0	0
	conferticostata Cragin	1	1(?)	0	0
Pectinacea	*Pecten (Camptonectes) insutus* Cragin.	6	6	1	1
	(*Entolium*) sp	7	14	1	1
	Plicatula sportella Cragin	1	1	0	0
	Lima interlineata Cragin	2	2	1(?)	1(?)
	riograndensis Cragin	3	3	0	0
Mytilacea	*Mytilus nuntius* Cragin	1	1	0	0
	Volsella maloniana (Cragin)	2	2	1	1
	geniculata (Cragin)	1	1	1	1
Anatinacea	*Pleuromya inconstans* Castillo and Aguilera.	10	28	1	1
	inconstans var. *curta* Cragin	1	?	1	?
	Pholadomya tosta (Cragin)	2	2	1	1
	marcoui Cragin	1	?	1	?
	paucicosta Roemer?	5	7	1	1
	praeposita Cragin	1	?	0	0
	Thracia? maloniana Cragin	1	?	0	0
	Anatina obliquiplicata Cragin	3	3	1	1
	Anatina? pliculifera Cragin	1	1	1	1
Cypricardiacea	*Artica cogeroi* (Castillo and Aguilera).	2	2	1	1
	Artica? streeruwitzii (Cragin)	1	?	1	?
Astartacea	*Astarte breviacola* Cragin	5	8	1	1
	malonensis Cragin	11	23	1	1
	posticalva Cragin	1	4	0	0
	Astrate? isodontoides Cragin	1	1(?)	0	0
	craticula Cragin	4	6	0	0
Lucinacea	*Lucina potosina* Castillo and Aguilera.	6	10	0	0
	potosina var. *metrica* Cragin	7	12	1	1
	planiuscula Cragin	3	3	0	0
	Lucina? emarginata Cragin	1	?	0	0
	Unicardium? semirotundum Cragin.	4	4	1	1
	transversum Cragin	3	?	0	0
Veneracea	*Tapes? cuneovatus* Cragin	3	3	1	1
	Ptychomya stantoni Cragin	3	3	0	0
Myacea	*Corbula? maloniana* Cragin	1	1	1	1
Adesmacea	*Martesia maloniana* Cragin	2	2	0	0

[1] Stoyanow (1949, p. 70–77) has emended this species and reassigned part of the type material to *Trigonia maloneana* Stoyanow, *T. maloneana* Stoyanow var., *T.* sp. and *T. dumblei* Stoyanow. Presumably all these are restricted to the lower member of the Malone Formation.

[3] Arkell (1956, p. 567) stated that *Lithacoceras? malonianum* should perhaps be assigned to *Progeronia* and that *L.? shuleri* is possibly a deformed *Katroliceras* or *Subdichotomoceras*.

people have searched with considerable care in a small area where exposures are good. Of the species described by Cragin, 13 were based on single specimens, and roughly 45 percent of the total were based on five or fewer specimens, from one or two stratigraphic units, in one or two localities. Only 12 of the total number occur in as many as 5 different localities. The only pelecypods that are fairly common are *Gryphaea. Pleuromya*, *Pinna*, *Astarte*, *Lucina*, *Trigonia*, and *Pecten*.

Gryphaea forms whole beds of shelly limestone and also occurs individually associated with a wide variety of other mollusks. The thick shells of these sedentary oysters remain well preserved, the valves being articulated; but generally, because the fossils are tightly cemented together, good specimens are difficult to obtain.

Pleuromya inconstans Castillo and Aguilera occurs as perfectly preserved individuals with the valves articulated and closed. The thin calcitic shell is preserved on most embedded specimens but breaks away easily on weathering, leaving internal molds. It was probably a burrowing clam, and its good preservation suggests that many individuals died while embedded in sediment. The same may have been true of *Pinna quadrifrons* Cragin, which also is well preserved; its elongate pyramidal shells can be broken from the rock without destroying the shelly material.

Astarte is well represented by number of individuals of each species and by kinds of species. *Astarte malonensis* Cragin, the largest and most common, occurs both as single valves and as whole shells, some of which were buried with valves closed, others opened wide. A few are preserved in position of life, with hinges upward, but most lie with the plane of symmetry in the plane of the bedding. The same is true also of the flat lenticular shells of *Lucina* commonly found with them.

Large shells of *Trigonia vyschetzkii* Cragin are also fairly abundant, generally preserved with the valves together. The shells are thick but break away readily from internal molds and are difficult to get out of the rock.

Scallops are present in considerable variety and number, the most abundant being an *Entolium*, not described by Cragin, whose single valves about an inch long are common in septarian limestone near the base of the formation in the Malone Mountains.

WORMS

The polychaete worm *Serpula*, of which two varieties and a possible third were distinguished by Cragin (1905, p. 37, pl. 2), is associated throughout the lower member with a wide variety of other fossils. It forms hollow calcareous tubes 1 to 8 mm in diameter in limestone and in places occurs in sandy rock, mostly as bundles of subparallel individuals. Some single tubes are wound in irregular spirals. The aggregates are several inches across and have irregular gross shapes and jagged edges, suggesting that these are fragments of larger masses.

Cylindrical elongate casts also believed to be of worms occur in some beds of sandy shale and sandstone in the lower member, especially near the base in the Malone Mountains. Commonly they occur to the exclusion of other types of fossils and make intricate patterns on the bedding surfaces.

ECHINOIDS

Cragin (1905, p. 16–18) found no echinoids in the Malone Hills but described fragments collected by Stanton from the Malone Mountains; these he referred to *Holectypus*? and *Pygurus*. Specimens collected by us also are from the Malone Mountains and are fragmentary and add nothing of taxonomic significance. All came from the lower member of the Malone Formation, mostly from between 400 and 450 feet below the top. Stanton's specimens came from unit 5 of his stratigraphic section, 435 feet below the top.

VERTEBRATES

Cycloid fish scales, one tooth, and several fragmentary bones, probably of marine reptiles, were described by Cragin (1905, p. 109) from our lower member in the Malone Hills. Large bone fragments have also been observed in the lower member south of Gypsum switch at an horizon approximately 70 feet above the base of the formation (Albritton, 1938, p. 1775).

PLANTS

Silicified branches and logs are scattered sparsely through the lower member and are most abundant in the basal 200 feet. Larger fragments lie parallel with the bedding and represent driftwood that became waterlogged, sank to the bottom, and was covered with sediment, later to be replaced with silica. The largest specimen is 15 feet long and 2 feet thick and is embedded in conglomerate in section 12 (pl. 2). Many of the logs are perforated by the clam, *Martesia maloniana* Cragin, whose shells occur inside some of these borings (Cragin, 1905, p. 87).

AGE AND CORRELATION

The ammonites in the Malone Formation indicate that it is of Late Jurassic age. The Kimmeridgian Stage is represented by beds in the lower member that contain *Idoceras*, and the Portlandian Stage—or

Tithonian, if the Portlandian is not valid beyond the limits of northwestern Europe (Arkell, 1956, p. 8)—by beds in the upper member that contain *Kossmatia.* The zones of these two ammonites are indicated on the stratigraphic diagram (fig. 21), but, owing to the sporadic distribution of these fossils, the zonal boundaries must be regarded as tentative.

Figure 26 summarizes available information on distribution of ammonite species in the Malone Formation of the Malone Mountains. It shows that no ammonites have been found either at the very top, at the bottom, or throughout the greater part of the upper half. Future collections may establish other zones in the Kimmeridgian and perhaps even extend the stratigraphic range downward into the Oxfordian or upward into the Portlandian.

Only three of the ammonite species are identical with those in the Mexican Jurassic, although many genera are common to both areas. As table 8 shows, these fall within two of the eight parts into which the Jurassic of Mexico has been divided (Imlay, 1939, tables 3–10).

The Late Jurassic age of the Malone Formation was first determined by Cragin (1905, p. 20–21) and was confirmed by Uhlig (1907) in his review of Cragin's

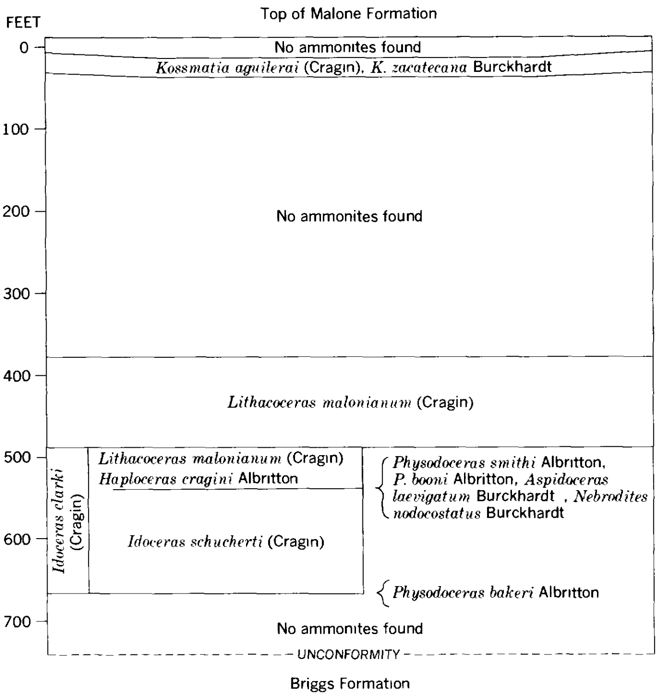

FIGURE 26.—Distribution of ammonite species in Malone Formation in Malone Mountains. Near the southeast end of the Malone Mountains, *Aspidoceras laevigatum* occurs about 50 feet above the base of the Malone Formation and is below the horizon at which *Physodoceras bakeri* was found in that area. Here the latter species occurs about 75 feet above the base of the formation and is associated with *Haploceras cragini.* These horizons could not, however, be determined with respect to the top of the formation.

bulletin. Neither indicated an age earlier than upper Portlandian, but Burckhardt (1912, p. 218; 1930, p. 82–83) pointed out that *Idoceras* indicated the presence of the Kimmeridgian Stage as well. L. F. Spath (in Kitchin, 1926, p. 457–458) cited the species of *Idoceras* as indicative of the middle Kimmeridgian, the species of *Haploceras*, *Lithacoceras*, and *Aspidoceras* as middle or upper Kimmeridgian, and the *Kossmatia* as possibly upper Portlandian. Imlay (1940a, p. 120) correlated the Malone Formation with the La Casita Formation (Kimmeridgian and Portlandian) of the Saltillo-Torreon area in Mexico.

Assignment of the Malone Formation to the Late Jurassic is strengthened by the occurrence of many of the Malone pelecypods in Upper Jurassic rocks of Mexico (Imlay, 1940b). These include Cragin's *Trigonia munita*, *T. vyschetzkii*, *T.* aff. *proscabra*, *Pinna quadrifrons*? and *Astarte malonensis*, as well as *Pholadomya paucicosta*? Roemer. Other pelecypods known from various localities in the Mexican Jurassic and also found in the Malone Formation are *Trigonia calderoni* (Castillo and Aguilera), *Cucullaea catorcensis* Castillo and Aguilera, *Gryphaea* sp. cf. *G. mexicana* Felix, *Exogyra* sp. cf. *E. potosina* Castillo and Aguilera, *Artica coteroi* (Castillo and Aguilera), *Lucina potosina* Castillo and Aguilera, and *Pleuromya*? *inconstans* Castillo and Aguilera.

The Late Jurassic age of the Malone Formation, as we have restricted it, now seems fairly well established, but there was a time when many geologists believed that the fauna described by Cragin was partly of Early Cretaceous age. There has never been any doubt that the ammonites were Jurassic, but a considerable issue has been raised regarding the age of the pelecypods, including several of the species just listed. The history of this problem is briefly reviewed in the following section.

THE MALONE CONTROVERSY

Burckhardt (1912) noted that faunas of two different ages might have been mixed in the collection described by Cragin. According to Burckhardt, the ammonites from the Malone Mountains and Malone Hills area are definitely Jurassic, but *Trigonia vyschetzkii* Cragin and *Ptychomya* suggest an Early Cretaceous age.

Kitchin (1926), elaborating on this suggestion, accepted the Jurassic age of the ammonites, largely on the authority of Uhlig (1907) and Spath (in Kitchin, 1926, p. 457–458), but maintained that many of the pelecypods—notably the Trigoniae—were Cretaceous. Uhlig had suggested that pelecypods of Early Cretaceous aspect might have originated during the Late Jurassic, but Kitchin asserted the clams in question

TABLE 8.—*Ammonites reported from northern and eastern Mexico and from Malone Mountains*

Stage		Subdivisions (after L. F. Spath, 1933; see Imlay, 1939, table 10)		Ammonites reported from northern and eastern Mexico and from Malone Mountains	
				Genera	Species
Tithonian		*Substeuroceras* and *Proniceras* beds		None	None.
Portlandian		*Durangites* and *Kossmatia* beds		*Kossmatia*	*K. zacatecana* Burckhardt.
Kimmeridgian	Upper	*Torquatisphinctes* and *Mazapilites* beds		*Physodoceras* *Aspidoceras* *Haploceras*	None.
Kimmeridgian	Lower and Middle	*Waagenia* beds		*Physodoceras*	None.
Kimmeridgian	Lower and Middle	*Idoceras* beds	*Glochiceras* gr. of *fialar* (Oppel) and *Idoceras* gr. of *durangense* Burckhardt	*Haploceras* *Aspidoceras* *Nebrodites* *Idoceras*	*Aspidoceras laevigatum* Burckhardt; *Nebrodites nodosocostatus* Burck.
Kimmeridgian	Lower and Middle	*Idoceras* beds	*Idoceras* gr. of *balderus* (Oppel)	*Aspidoceras* *Idoceras* *Nebrodites*	None.
Oxfordian	Upper			*Aspidoceras* *Lithacoceras*	None.
Oxfordian	Middle			None	None.

were too specialized to have survived any long span of time.

In 1930, Burckhardt listed the pelecypods of the Malone fauna that indicated an Early Cretaceous age, and in 1932, Adkins (1932, p. 255–256), following Kitchin, revised the stratigraphy to separate the Jurassic from the Cretaceous fossils. Stoyanow (1936) reported the presence of the Malone fauna at the base of the rocks of Comanche age in Arizona. That same year, Kellum (1936, p. 1063–1069) reported the Malone bivalve fauna from rocks of supposed Early Cretaceous age in the Torreon area, Mexico.

After studying the Malone Mountains and Malone Hills, we found the situation to be as Cragin and Stanton had originally claimed; at a number of localities the same pelecypods that Kitchin had cited as evidence of Early Cretaceous age were found in the same layers with ammonites everyone had agreed were Jurassic. With the possible exception of *Exogyra potosina* Castillo and Aguilera, all the disputed pelecypods occur either in the same zone with or in beds stratigraphically below *Kossmatia aguilerae* (Cragin).

After studies of the Early Cretaceous fauna of northern Mexico, Imlay (1940a, p. 135) stated:

> Concerning the controversy about the age of the pelecypods of the Malone formation of Texas * * * the writer can state that the known Neocomian faunas of Mexico are definitely distinct from the Malone fauna, whereas the Upper Jurassic faunas of Mexico contain many species which are identical with species in the Malone fauna.

Stoyanow's subsequent studies of the Lower Cretaceous in Arizona and of the problems related to the age of the Malone fauna have brought him to accept the Jurassic age of the Trigoniae and other pelecypods described by Cragin. Stoyanow (1949, p. 44–45, 48) has analyzed the Malone controversy at length, concluding that:

> Kitchin's error perhaps was not in the evaluation of the ontogenetic and phylogenetic development of the southern Cretaceous Trigoniae, which in the main is well worked out, considering the available paleontological material and geological information, and is even now a solid foundation for any further research in this line, but in the misinterpretation of stable and variable characters in their relation to the scale of time. The features that were supposed to indicate a rapid and geologically short specialization * * * appear to have been introduced earlier and remained, with slight variations, through the Lower Cretaceous.
>
> * * * * *
>
> the presence of Trigoniae with such strong Cretaceous affinities in the strata of Malone age is quite unique. It does not imply a later age than Jurassic for the strata in which these Trigoniae occur in a close association with the Malone ammonites, but it certainly foreshortens the perspective of the time span which separates these strata from the Cretaceous and through which the development of the Trigoniae of the established types continued uninterruptedly.

The Malone controversy defined in terms of the issue raised by Kitchin, then, has been settled.

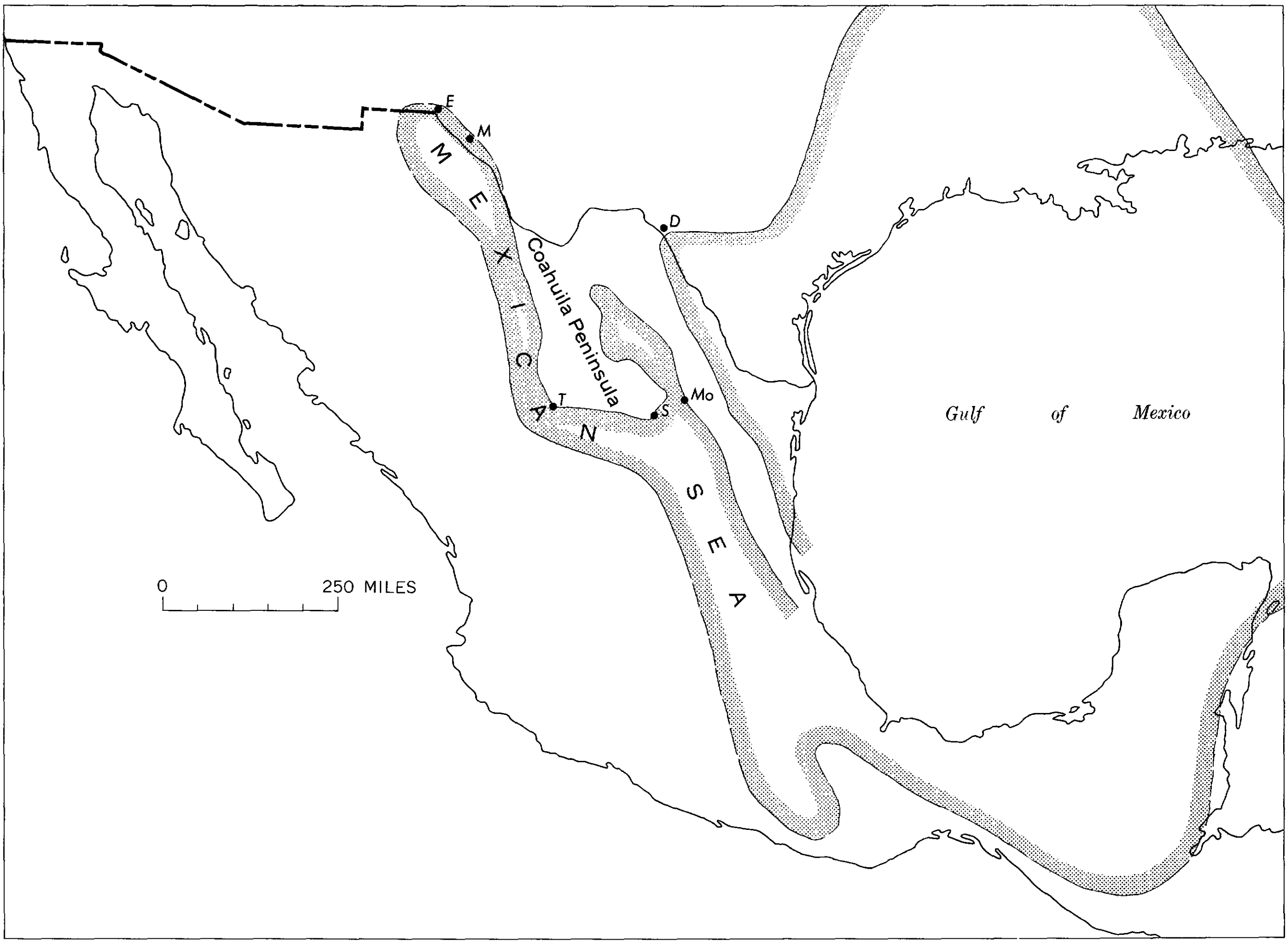

FIGURE 27.—Mexico and part of the United States and approximate position of the Mexican sea during Late Jurassic time. Seaward side of shore stippled. Dashed lines show areas where position of shore is least certain. *M*, Malone Mountains; *E*, El Paso; *T*, Torreon; *S*, Saltillo; *Mo*, Monterrey; and *D*, Del Rio. (After Humphrey, 1956, p. 31, and Imlay, 1943b, p. 1509.)

Further regarding the age of the beds, the question has been raised that fossil evidence for Lower Cretaceous rocks in the Malone Mountains area is inadequate and that until "undoubted Lower Cretaceous fossils are found in the Malone Mountains, it does not seem necessary to modify the concept of the Malone formation" (Imlay, 1943b, p. 1485). This matter regarding Early Cretaceous fossils is discussed further in the section on the Torcer Formation (p. 41–42).

CONDITIONS OF DEPOSITION

At the end of the Paleozoic Era, the Sierra Blanca area was presumably land, which persisted through Triassic and most of Jurassic time. Mexico to the south, however, became increasingly inundated (fig. 27). During Late Jurassic time, the Mexican seaways extended northward slightly beyond the present site of the Malone Mountains, as attested by the sedimentary rocks of the Malone Formation containing stony corals, ammonites, and other marine invertebrates. The original position of these rocks was southwest of the present Malone Mountains; the rocks have been transported northeastward at least several miles by thrust faulting.

Wherever the site of deposition may have been, land was nearby, for silicified branches and trunks of trees are mingled with the marine invertebrates, especially in the lower beds. The surface on which the Upper Jurassic rocks were deposited was irregular and probably had several hundred feet of relief. As shown in plate 2, the Malone Formation thins eastward against the flank of an anticlinal mountain of dolomite of Permian age and thickens over a valley that was cut in softer gypsiferous beds. This mountain was at least 800 feet high—as high as any in the present Malone Mountains. One can imagine that, as the sea advanced, this mountain and similar prominences first became islands and then submerged banks.

The main shoreline of the seaway was likely diversified by inlets along drowned streams and by headlands. The contrasts in terrain were probably reflected in the sediment; steep headlands might shed gravels and coarse sand into the water, while nearby estuaries were receiving finer mud.

The new seaway was colonized by worms that built tubes or burrowed in the mud, small clams such as *Lucina* and *Gryphaea*, and the little *Martesia* that bored into the driftwood. These were followed by various pelecypods and marine snails and also by many cephalopods.

During deposition of the lower part of the Malone Formation, the gypsum of the Briggs Formation must have been at the surface along the shore, and some of this may have been reworked into the Jurassic deposits. The gypsum of the Briggs Formation is probably a chemical precipitate, but field relations suggest that the gypsiferous beds in the Malone are largely detrital. The gypsum in the Malone is impure, forms thinly bedded rather than massive deposits, and is associated with detrital quartzose rocks rather than with carbonate rocks. Transportation and accumulation of detrital gypsum may have been similar to that occurring now near rock gypsum of the Briggs Formation near Gypsum switch, where crusts, crumbs, and individual crystals of gypsum are moved as fragments and mixed with sand along Arroyo Balluco (p. 115–116). Lithification of some of these aggregates would make rock much like the gypsiferous sandstones of the Malone Formation.

The clastic sediments of the lower part of the Malone are poorly sorted; the finer beds commonly contain pebbles and the coarser ones contain silt in their matrices. The sediments must not have been worked over much by currents after they were deposited but were buried fairly rapidly, entombing sedentary benthonic animals in the process. Corals, tube-building worms, and oysters were abundant on the bottom, but the continued influx of sediments seems to have prevented their forming colonies.

After initial irregularities of the sea floor were leveled by fill, new sediment was not added rapidly enough to prevent algae from building coalescing biostromal masses. By the extraction of carbon dioxide from the sea water, these plants caused the precipitation of calcium carbonate and the building of limestone masses. In time, the algae spread over wide areas in environments not favorable to other kinds of bottom-living organisms; marginal to these algal gardens were sandy or gravelly bottoms, on which scallops as well as the thick-shelled oysters *Exogyra* and *Astarte* flourished.

The waters in which the Malone sediments were deposited were relatively shallow. None of the beds contains mud cracks, but within the zone of *Idoceras*, the lowest in the Malone Formation, the ammonites are predominantly compressed and smooth, whereas above this zone in both the lower and the upper member, they are sculptured. According to Scott (1940), ammonites with compressed shells lived in water between 5 and 20 fathoms deep, and those with sculptured shells between 20 and 100 fathoms. The abundant algal limestone in the upper member suggests sunlit bottoms less than a hundred fathoms below the surface.

CRETACEOUS SYSTEM

LOWER CRETACEOUS(?) SERIES

TORCER FORMATION

DEFINITION

The Torcer Formation was named by Adkins (1932, p. 287) for exposures near Torcer station on the Southern Pacific Lines. It is 400 feet thick and consists largely of limestone, except for a persistent layer of brown quartzite and siliceous conglomerate, about 40 feet thick, at the base.

The formation rests conformably on the Malone Formation. The contact is gradational, calcareous sandstone of the older formation blending with the lower siliceous layers of the younger through an interval of 2 to 10 feet.

The quartzitic unit is the most distinctive and conspicuous in the Malone Mountains, and, depending on the structure, forms the caps of mesas, a line of cliffs, or serrate hogbacks (fig. 28). Taff (1891, p. 722–723) apparently included this unit at two different horizons in his stratigraphic section, as his unit 10 and also as units 12 and 13; the upper part of his section is thus about twice too thick. Stanton (1905, p. 25–26) placed the quartzitic beds in proper sequence near the top of his section in the Malone Mountains. Near Gypsum switch, Baker (1927, p. 15) collected an ammonite, "*Astieria*," which he considered to be indicative of Early Cretaceous age. Adkins (1932, p. 286–291) accepted this fact as confirmation of Kitchin's views on the age of the Malone pelecypods, applied the name Torcer to "the Cretaceous portion of Cragin's 'Malone formation' " and to the quartzitic and younger beds in the Malone Mountains, but referred to Taff's early and incorrect stratigraphic section. Albritton (1938, p. 1764–1766) amended this definition by stating that unit 11 of the section used by Adkins includes all the upper member of the Malone (restricted) and part of the lower.

FIGURE 28.—Basal quartzitic beds of Torcer Formation forming serrate hogback across valley. In Malone Mountains, 0.7 mile southwest of Torcer.

The best exposed and thickest section of the Torcer crops out along the northeast front of the Malone Mountains due south of Torcer station and is designated as the reference section (Albritton, 1938, sec. 21, p. 1795–1796).

SECTION 15.—*Reference section of the Torcer Formation*

[Northeast slope of Malone Mountains below hill 5016, 2¾ miles north-northwest of Hilltop Cafe; traverse 15 shown on pl. 1. (Section 21 of Albritton, 1938, p. 1795–1796)]

Top eroded.

Lower Cretaceous(?)—Torcer Formation:	*Thickness (feet)*
28. Limestone, dense, black, gray-weathering, in beds averaging 3 ft thick; numerous small smooth-shelled gastropods	32
27. Limestone, dense, black, buff- to gray-weathering, locally conglomeratic	15
26. Limestone, dense, black, gray-weathering, in beds as much as 3 ft thick; contains numerous small, smooth-shelled gastropods	22
25. Limestone, dense, black, buff- to gray-weathering, locally pebbly to conglomeratic; forms ridge	33
24. Sandstone, gray, brown- to gray-weathering, and granule conglomerate	22
23. Limestone, dense, dark gray-weathering; has splintery fracture	8
22. Shale, gray, sandy	12
21. Limestone, dense, black, gray-weathering; contains numerous small smooth-shelled gastropods	3

SECTION 15.—*Reference section of the Torcer Formation*—Con.

Lower Cretaceous(?)—Torcer Formation—Continued	*Thickness (feet)*
20. Limestone, gray to black, shaly; poorly exposed	5
19. Limestone, dense, black, gray-weathering, contains numerous small gastropods	4
18. Shale, gray, sandy	8
17. Sandstone and grit, gray, brown-weathering, calcareous; beds average approximately 1.5 ft thick	17
16. Limestone, dense, black, pebbly; contains numerous small smooth-shelled gastropods; beds as much as 5 ft thick; forms conspicuous ridge	22
15. Shale, gray, sandy	2
14. Limestone, black, gray-weathering, in beds as much as 2 ft thick	33
13. Limestone, black, gray-weathering, in beds averaging 5 ft thick; contains numerous small, smooth-shelled gastropods	34
12. Shale, gray, sandy, calcareous	1
11. Limestone, black, gray-weathering, shaly; poorly exposed	35
10. Limestone, black, brown-weathering, arenaceous	2
9. Limestone, black, gray-weathering	35
8. Conglomerate of chert-pebbles, gray, brown-weathering; has well-rounded pebbles averaging a quarter of an inch in diameter	1
7. Unexposed	5.5
6. Limestone, black, gray-weathering, concretionary; has pisolites as much as 2 in. in diameter enclosing chert-pebble nuclei	1.5
5. Unexposed; slope strewn with fragments of gray limestone	9

SECTION 15.—*Reference section of the Torcer Formation*—Con.

	Thickness (feet)
Lower Cretaceous(?)—Torcer Formation—Continued	
4. Conglomerate of chert and limestone pebbles, gray, brown-weathering; matrix of arenaceous limestone; well-rounded phenoclasts, averaging half an inch or less in diameter; grades laterally into sandy and pebbly limestone	2.5
3. Limestone, black, gray-weathering, arenaceous; scattered chert pebbles toward top; beds as much as 2 ft thick	10.5
2. Sandstone, gray to buff, quartzitic; interbedded lentils of well-rounded chert pebbles averaging half an inch in diameter	25
Total preserved thickness	400
Upper Jurassic—Malone Formation (restricted), upper member:	
1. Limestone, dense, black, gray-weathering; breaks with subconchoidal to hackly fracture; in beds from 1 to 10 ft thick; base not exposed	374.0

BASAL QUARTZITIC BEDS

The basal quartzitic unit contains all the dominantly sandy or conglomeratic beds at the base of the Torcer Formation. It is thickest, about 50 feet, in the central part of the Malone Mountains and thins northwestward to 40 feet, and southeastward, in the foothills between the Malone and Quitman Mountains, to 10 feet. Its base appears to maintain a fairly constant stratigraphic position, despite its gradational relation to the uppermost layers of the Malone Formation. The irregularities in thickness seem to be due to interfingering of the upper part with impure pebbly limestone, as observed along the front of the mountains south and west of Torcer station.

Fresh surfaces of the quartzite are brownish gray, but the conglomerate is mottled in various shades of gray, grayish white, and brown, owing to differences in color of the pebbles. Weathered surfaces of the quartzite and conglomerate are rusty brown, in contrast to the drab gray of the limestones above and below.

The principal bedding surfaces show as subparallel cracks between 2 and 3 feet apart, the beds of quartzite being massive or laminated internally. Locally, beds have small-scale cross-laminations like those associated with ripples, but no rippled surfaces were observed. Most of the quartzitic beds are pebbly, and there are all gradations between conglomerate and quartzite. Some units consist of alternating quartzite and conglomerate in layers a few inches thick.

Quartzite and sandstone make up about 90 percent of the basal unit and consist of rounded to subangular grains of quartz and chert forming a medium to coarse aggregate. Quartz grains predominate, but chert grains account for as much as 20 percent of the detrital fraction. The cement is of quartz, commonly grown in optical continuity with adjacent sand grains; therefore, the rock in thin section appears as a mosaic of quartz crystals enclosing chert grains.

The fragments in the conglomerate are well-rounded granules and pebbles, mostly ¼ to 1 inch in diameter, but include sparse cobbles as much as 3 inches across. Most of these are siliceous, although pebbles of limestone occur in small numbers. Particles of gray or brownish chert are mixed in about equal proportions with pebbles of milky quartz. The conglomerate is cemented principally by quartz, but some beds are cemented almost entirely by calcite; the more calcareous layers commonly grade into arenaceous limestone.

In most places the siliceous rocks either are closely jointed or are cut by veins of milky quartz and calcite that cross the bedding at high angles. On weathering, the strata break along these planes of weakness to form a rubble of slabs and splinters.

BEDS ABOVE THE BASAL QUARTZITIC UNIT

The Torcer consists principally of limestone and minor amounts of interbedded sandstone, sandy shale, and conglomerate (fig. 29). Limestone amounts to 80 percent or more of the section above the quartzitic beds. It forms units as much as 125 feet thick and is evenly bedded in layers 1 to 5 feet thick. Most layers are dark gray and weather lighter gray, but some ferruginous beds weather brown. Most of the rock is fine textured and breaks with subconchoidal fracture. Sections of tiny gastropods are visible on weathered surfaces but can rarely be broken from the rock. In thin section, the limestone proves to be less homogeneous than one would suspect; random angular grains of quartz silt and very fine grained sand account for 5 to 10 percent of its volume. Very fine or fine sand-sized rounded limestone fragments are mingled with the grains of quartz. Quartz and limestone grains and a variable quantity of gastropod and pelecypod shells are set in a cryptocrystalline carbonate matrix (fig. 30), which may contain as much as 10 percent of clay.

Analyses of two specimens given in table 9 show that the limestones contain little magnesium but contain a variable amount of insoluble materials.

TABLE 9.—*Analyses of limestone from the Torcer Formation*
[Analyst, R. G. Guerrero 1952]

Locality	Analyses (percent)			
	Acid insoluble	$CaCO_3$	$MgCO_3$	Total
One mile south of Torcer station; unit 9 of reference section	4.06	92.02	1.90	97.98
Southeast end of Malone Mountains	19.04	77.85	.86	97.75

FIGURE 29.—Limestone beds of Torcer Formation in syncline along northeast front of Malone Mountains, south of Torcer station.

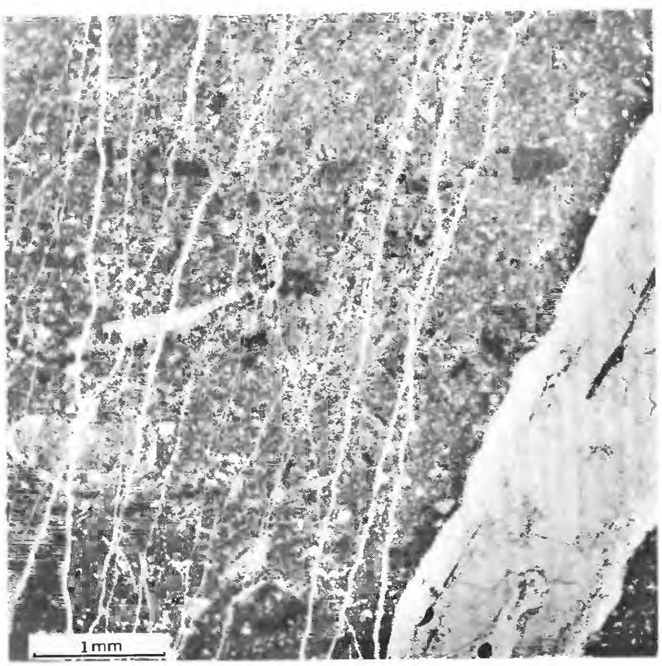

FIGURE 30.—Impure limestone from Torcer Formation, southeast end of Malone Mountains. Quartz silt (white grains), fine shell debris, and scattered rock fragments are set in matrix of cryptocrystalline calcite. The veinlets, including large white band, are also of calcite.

Sandstone is sporadic above the basal quartzitic layers, generally accounting for no more than 12 percent of the exposed section. Sandy units are mostly thin bedded and cross-laminated and a few feet to slightly more than 20 feet thick. The sand is a mixture of medium-sized rounded limestone grains and subordinate rounded to subangular quartz grains. The rock is cemented by calcite.

Many of the limestone beds contain scattered rounded pebbles of gray limestone, which locally are concentrated in lentils. Few of the pebbles exceed 2 inches in diameter. Such pebbly beds are inconspicuous because the clastic particles and the matrix are both dark gray.

Gray sandy calcareous shale forms partings between some of the limestone beds and forms a few layers 1 to 12 feet thick.

FOSSILS AND AGE

Adkins (1932, p. 287), in defining the Torcer Formation, placed the beds containing the ammonite "*Astieria*" collected by Baker (1927, p. 15) at the bottom of the unit and noted also that another ribbed Cretaceous ammonite had been collected from this locality. Impressions of compressed and costate ammonites are fairly common in basal beds of the Torcer, but they are mostly imperfect, and all are exceedingly difficult to break from the rock. Fragments collected by us were identified by Prof. Gayle Scott as *Neocomites* sp. He believed that these fragments were sufficient to establish the age of the Torcer as Early Cretaceous, and Arkell (1956, p. 566) has concurred in this opinion. Albritton (1937b, p. 408–409; 1938, p. 1766) described one of the fragments as *Neocomites* cf. *N. indicus* Uhlig, a species known from the Lower Cretaceous (Valanginian) of the Himalayas.

Foraminifers occur sparingly in the basal quartzitic beds. Sandstone beds between 3 and 20 feet above the base yielded both arenaceous and calcareous tests of *Saccammina* cf. *S. sphaerica* Sars, *Lagena*? sp., *Gümbelina paucistriata* Albritton, and *Anomalina torcerensis* Albritton (Albritton, 1937a). Sandstone and arenaceous limestone directly above and below the beds containing the foraminifers contain poorly preserved pelecypods, including *Exogyra* aff. *E. potosina* Castillo and Aguilera and *Pleuromya* sp.

The beds above the basal quartzite and conglomerate contain no ammonites, thick-shelled pelecypods, or calcareous foraminifers. Small smooth- and thin-shelled gastropods (*Viviparus*?) are abundant in many of the limestone beds and are associated in places with pelecypods resembling the modern genus *Unio*. The arenaceous foraminifer *Ammobaculites subcretaceous* Cushman and Alexander occurs in sandy shale 100 feet above the base.

An Early Cretaceous—as contrasted to Late Jurassic—age of the Torcer Formation is suggested not only by the ribbed ammonites but also by the foraminiferal genera *Gümbelina* and *Anomalina* (Albritton, 1938, p. 1766). *Gümbelina* is generally considered to be characteristic of the Cretaceous and early Tertiary and in Texas is more abundant in the Upper than in the Lower Cretaceous rocks. *Anomalina* ranges from Early Cretaceous to Recent in age and probably does not extend into the Jurassic Period (Cushman, 1948, p. 332; Glaessner, 1948, p. 148). *Ammobaculites* is known from rocks older than Cretaceous, but the species in the Torcer is either the same or very close to Cushman and Alexander's *A. subcretaceous*, first described from the Goodland Limestone (Lower Cretaceous) of Texas.

On the other hand, the fossils are few in number and variety and are not unequivocal proof of a Cretaceous age of the Torcer (Imlay, 1943b, p. 1485, 1492). R. W. Imlay (written commun., 1961) considered that the Torcer Formation may be in part or all of Jurassic age. This opinion is based largely on two considerations. First, he considers that the ammonite from the Torcer Formation identified as *Neocomites* cf. *N. indicus* Uhlig more likely belongs to *Kossmatia*, a Late Jurassic genus. Second, a limestone bed at or near the top of the Malone Formation has furnished the ammonites *Subplanites*?, *Virgatosphinctes*, and *Kossmatia* (USGS Mesozoic loc. 26956) which, in association, are not likely to be younger than the early Portlandian and could be as old as the late Kimmeridgian of northwest Europe. (See Arkell, 1957, p. L323, L329, L330.) These ammonites, collected recently by Roy T. Hazzard, represent the same genera and in part the same species as some ammonites from the Placer de Guadalupe area, Chihuahua (Imlay, 1943a), that Arkell (1956, p. 562) assigns an early Tithonian age. (See definition in Arkell, 1956, p. 8, 12, 613.) If the topmost bed of the Malone Formation is of early Tithonian age, however, then, according to Imlay, part or all of the conformably overlying Torcer Formation must be of Jurassic age also. Evidently the determination of the age of the Torcer Formation must await the discovery of more diagnostic or better preserved fossils.

Until more fossils are known, the age of the Torcer Formation is questionable. Although in our opinion evidence now available would seem to favor an Early Cretaceous age, a query is used to express the doubt.

CONDITIONS OF DEPOSITION

The ammonites and calcareous foraminifers indicate that the basal siliceous beds of the Torcer Formation were deposited in marine waters. The limestones above these beds, on the other hand, may have been deposited as calcareous muds in waters of less than normal salinity. The gastropod *Viviparus* seems to be a fresh-water form (Stanton, 1905, p. 26), and pelecypods associated with it in some beds resemble the fresh-water *Unio*. The arenaceous foraminifer *Ammobaculites* is today abundant in the brackish lakes and swamps on the landward side of the shore in the region of the Mississippi delta (Lowman, 1949, p. 1952–1953). No fossil of exclusively marine organisms has been reported from the upper calcareous portion of the Torcer, whereas every fossil that has been found in these beds resembles living groups that inhabit fresh or brackish waters.

In contrast to the underlying Malone Formation, the sandstone and conglomerate of the basal part of the Torcer is better sorted and is composed almost entirely of relatively hard materials. Possibly the sand and gravel of which these beds are made were laid down on bottoms that were long agitated by waves and currents, so that the softer fragments of limestone were mostly ground to powder and swept away, leaving a residue of quartz and chert. Such conditions conceivably might have resulted from the building up of the bottoms, toward the end of Malone time, to surfaces of equilibrium over which sediment was spread and winnowed. This fact suggests a pause in subsidence along the northern arm of the Mexican embayment. Under such conditions growth of deltas and bars might have impounded bodies of brackish water in which the calcareous muds of the upper part of the Torcer accumulated.

LOWER CRETACEOUS SERIES

ETHOLEN CONGLOMERATE

DEFINITION

Taff (1891, p. 724) applied the name Etholen Bed to rocks exposed on and near Etholen Knobs between the Quitman Mountains and Sierra Blanca Peak, but he also used the name for beds elsewhere in the region that are now known to be of different ages. These beds include parts of the present Yucca Formation, Malone Formation, and Leonard Series. Baker (1927, p. 15–18) attached conglomerate to the name, but he also included units in the formation that probably are parts of other formations. The Etholen Conglomerate as we define it in the Sierra Blanca area is restricted to include only chiefly conglomerate beds near the Etholen Knobs and Etholen Hill. Here the following reference section is exposed.

SECTION 16.—*Reference section of Etholen Conglomerate*

[West Etholen Knob; traverse 16 shown on pl. 1]

	Thickness (feet)
Top eroded.	
Lower Cretaceous—Etholen Conglomerate:	
3. Conglomerate, gray; beds 6 in. to 12 ft thick, bedding obscure to well defined; fragments range from pebbles to boulders—the largest are 1½ ft long, but most are 1 to 4 in.; fragments of all sizes of gray, brown, buff, and tan massive or laminated limestones; some chert pebbles; a few interbedded gray limestone lentils 6 in. to 1½ ft thick and 2 to 6 ft long	190
2. Conglomerate, gray; beds 6 in. to 12 ft thick; fragments range from pebbles to boulders, most of which are ½ to 2½ in. in diameter; fragments are more rounded than in overlying unit and are chiefly gray, brown, buff, and tan limestone, containing some pink and red limestone and some chert	340
1. Conglomerate, gray; obscure beds 6 in. to 12 ft thick; most of fragments 1½ to 3 in. in diameter, but many limestone boulders 6 to 12 ft in diameter and a few angular limestone blocks 15 ft long; larger boulders chiefly in lower part. A limestone bed near base contains *Haplostiche texana* (Conrad) (identified by S. K. Fox); this bed is probably in place, but might be a large transported block. Base along Devil Ridge thrust; base of section not exposed	143
Total measured thickness	673

GENERAL FEATURES

The Etholen Conglomerate is about 700 feet thick. Its relations to other formations are obscure, as nearly all the contacts are covered by alluvium or are faulted, but evidence indicates that the Etholen is at the base of the Cretaceous sequence in the area. It rests with thrust fault contact on younger Cretaceous units and seems to underlie the Yucca Formation.

Most of the formation is covered with rubble, but it crops out in places on cliffy slopes and is well exposed in several quarries. Most of the formation is a thin- to thick-bedded conglomerate formed of pebbles, cobbles, and boulders, largely of gray limestone. Chert pebbles are scattered throughout the formation and in places form lentils. Limestone beds as much as 4 feet thick are interbedded in the lower part of the conglomerate on West Etholen Knob, and thinner limestone layers occur higher in the formation.

LITHOLOGY

Conglomerate makes up about 95 percent of the formation. The overall color is gray, but beds with abundant chert fragments are brown to greenish. Most of the fragments in the conglomerate are 1 to 8 inches in diameter, although boulders 1½ to 3 feet across are common. Near the base of the exposures on the west side of West Etholen Knob are some blocks up to 15 feet long. Exposures are too poor to indicate or reveal whether many of the limestone ledges are sedimentary beds or large blocks, but most of those longer than 15 feet are thought to be beds in place. Chert fragments are about 8 inches in maximum diameter. The limestone fragments are angular to rounded. All except the largest boulders and blocks have rounded edges; one well-rounded 6-foot boulder was noted. Cobbles of massive limestone are generally well rounded, whereas those of laminated limestone are tabular; in some beds most fragments are tabular. Nearly all the chert pebbles are rounded, although not as perfectly as the best rounded limestone pebbles. The conglomerate displays many degrees of sorting, from poor to excellent. Commonly, beds composed of 1- to 2-inch pebbles also contain 10- to 13-inch boulders. Some beds are made up entirely of cobbles or boulders.

Most of the varieties of limestone in the conglomerate fragments resemble those in the Permian rocks exposed to the northeast. Many of them contain crinoid stems, brachiopods, bryozoans, fusulinids, ammonoids, and solitary corals that are clearly Paleozoic and are probably of Permian age. No Cretaceous fossils were observed in the conglomerate fragments, nor do the limestone fragments closely resemble any local limestones of Cretaceous age. The rock types include: (1) light-gray limestone weathering light gray, (2) dark-gray to black limestone weathering gray, (3) gray thin-bedded limestone with beds ¼ to ½ inch thick, (4) gray evenly bedded limestone with light beds ¹⁄₁₆ inch and dark beds 1/8 to 1/4 inch thick, (5) gray laminated limestone, (6) gray limestone weathering light brown and yellow, (7) light yellowish-brown limestone weathering yellow to tan, (8) gray, light pinkish-gray, black, and dark-purple chert, of which the dark varieties are most common. Chert pebbles are mingled with limestone pebbles through much of the conglomerate; in the upper part of the formation along the western extension of Etholen Hill, a mass of conglomerate 100 feet thick consists entirely of chert pebbles.

The matrix of the limestone conglomerate consists of three kinds of material. One consists of fine to coarse quartz grains and accessory limestone particles with calcareous cement. Another is chiefly a mosaic of very fine grained angular limestone fragments. The third is white crystalline calcite. Conglomerates characterized by the various kinds of matrices grade into each other. The chert-pebble conglomerates are bound by siliceous cement.

Packing of pebbles and larger fragments is highly variable; in some beds, pebbles and cobbles are packed so tightly that there is little matrix; elsewhere cobbles are sparse through coarse sand and granule gravel. The more closely packed pebbles are commonly intergrown along stylolitic seams. The pebbles, cobbles, and boulders of the conglomerates generally show no preferred orientation, although a few flat pebbles lie parallel to the bedding.

Bedding surfaces in the conglomerate are parallel, clearly defined to obscure, and are spaced at intervals of 1/2 to 12 feet. Stratification is best developed in the finer grained rocks, especially those interbedded with lenses of limestone.

Lenses of gray limestone, sandy limestone, and calcareous sandstone are interbedded with the conglomerate. These are generally 3 inches to 3 feet thick and 2 to 20 feet long, but in the lower part of the formation near the west end of West Etholen Knob, limestone beds 4 feet thick are exposed on rubbly slopes. Some of these beds are probably continuous for 200 to 300 feet. Some of the thicker beds contain scattered pebbles of limestone and chert and nodules of chert. The limestone and sandy limestone beds have both sharp and gradational contacts with the conglomerate. These contacts are irregular in places, but none are distinctly channeled.

AGE AND CORRELATION

Because of its obscure relations to adjacent formations, the stratigraphic position of the Etholen Conglomerate is not clear, and it has been variously assigned. In his Etholen Bed Taff (1891, p. 724) included strata now known to be of Permian, Jurassic, and Cretaceous age. Baker (1927, p. 15–18) and Adkins (1932, p. 285 and fig. 15, p. 292) assigned the Etholen to the base of the Cretaceous, but Baker included other conglomerate beds that we now assign to the Yucca Formation. On the basis of its relations on Etholen Hill, Huffington (1943, p. 1008–1009) interpreted the Etholen as overlying the Washita Group, but we believe this superposition is the result of thrusting.

The Etholen is younger than the Permian, as its fragments contain Permian fossils, but the only indigenous fossils are arenaceous foraminifers in a limestone bed in the lower part of the formation on the west side of West Etholen Knob. These were identified by Steven K. Fox as *Haplostiche texana* (Conrad), which occurs commonly in Texas in the Grayson Shale (Del Rio Clay of former usage) low in the Upper Cretaceous sequence. This species has a much more extended range, however, occurring, for example, in the Sierra Blanca area in the Bluff Mesa and Finlay Limestones and in the rocks of Washita age.

According to the best available evidence the Etholen Conglomerate underlies the Yucca Formation and has a position low in the Lower Cretaceous Series. The Etholen is separated spatially from the Torcer Formation, but the Torcer Formation also seems to underlie the Yucca. As the Etholen and Torcer both appear to be in about the same part of the stratigraphic column, they may be equivalent, at least in part.

CONDITIONS OF DEPOSITION

The Etholen is a subaqueous deposit that probably accumulated in a local trough bordering a cliffy shore. The water at most times may have been fresher than ordinary sea water, and the prevailing climate along shore was likely more arid than humid.

The presence of foraminifers establishes a marine origin for the older beds. Limestone beds at various horizons from bottom to top likewise indicate deposition in standing water. The coarseness of the deposit suggests nearness to the source, an inference supported by the resemblance of limestone fragments in the conglomerate to those exposed nearby in the Paleozoic sequence. Huge angular slabs of limestone particularly on West Etholen Knob probably could not have been transported far by streams and must have toppled from cliffs rising from near the edge of the water. The roundness of smaller fragments may record the strength of the surf and the competence of streams draining a hilly hinterland. Detachment of blocks to supply the enormous quantity of limestone cobbles and pebbles is a process more effective in an arid climate than a humid one.

Any hypothesis for the origin of the Etholen should be compatible with what is known about the origin of the possibly equivalent Torcer Formation. Both appear to underlie the Yucca Formation conformably, and although their exposures are separated, they must have been deposited at about the same time in nearby areas.

Despite strong superficial differences between the Torcer and Etholen, both have features in common. In both, marine fossils occur in the lower parts; the upper part of the Etholen is unfossiliferous and that of the Torcer contains a fauna suggestive of fresh or brackish water. Both units contain more carbonate fragments than siliceous fragments, although the limestone particles in the Torcer are finer and more dispersed than in the Etholen. Perhaps the limestone of the Torcer represents the final stage in mechanical reduction of carbonate clasts. If so, the Etholen might then represent the near-shore part of a clastic carbonate deposit, and the Torcer, the offshore part, or at least one more thoroughly worked by shore currents.

Some explanation is nevertheless required for the present small distribution of the Etholen. Where pre-Cretaceous rocks are exposed nearby in the Finlay Mountains, the Malone Mountains, the west side of the northern part of the Quitman Mountains, and the Diablo Plateau to the northeast (King and Knight, 1944), the Etholen Conglomerate is lacking. The original area of deposition was thus limited on the west, north, and east, although it may have extended farther south and southeast.

Gravels accumulated near shore generally form rudely circular or elliptical bodies interbedded with other types of aquatic sediments (Twenhofel, 1947, p. 123). In the Sierra Blanca area, tectonic movements along the south edge of the platform may have helped localize the deposits by creating a structural basin as a catchment area, or the catchment area may have been a drowned erosional valley occurring along the strike of the Paleozoic rocks. In any event, the shore of Etholen time probably lay near the present south border of the Diablo Plateau.

YUCCA FORMATION

DEFINITION

The name Yucca Formation is derived from the Yucca Bed of Taff (1891, p. 725), named for Yucca Mesa, which was further described by Smith (1940, p. 623–625). Taff also used the name Mountain Bed for rocks near Quitman Gap now known to be the same as those of the Yucca. South of the report area, in the southern Quitman Mountains, Scott (1939, pl. 55) used the name Las Vigas Formation for probably equivalent strata and derived the name from the formation of that name to the southwest in Chihuahua, Mexico.

Exposures of the Yucca Formation, ranging from about 1,100 to 5,500 feet thick, are restricted almost entirely to the southeast quarter of the area, where the beds form a continuous strip along the southern part of the Quitman Mountains, around Zimpleman Pass in the northern part of the Quitman Mountains, along the slopes of Bluff and Yucca Mesas, and along both sides of Devil Ridge. In the southern Quitman Mountains, the Yucca forms ridges lower than the mountain crests to the east. It forms the steep slopes below the rims of Bluff and Yucca Mesas and a low ridge southwest of Devil Ridge. On the slopes of the mesas capped by limestone of the Bluff Mesa Formation, exposures of the Yucca are poor except for ledges of resistant sandstone and quartzite; shale and platy limestone beds of the Yucca weather to rubble-covered slopes.

GENERAL LITHOLOGY

The Yucca Formation includes multicolored rocks with conspicuous red and purple beds and consists of interbedded limestone, sandstone, shale, conglomerate, and many mixed and gradational types; but limestone is dominant in the north and sandstone in the south (figs. 31 and 32). Limestone makes up the major part of the sections at Bluff Mesa, Yucca Mesa, and Devil Ridge, but there is less limestone than sandstone at Quitman Gap; and farther south in the Quitman Mountains, sandstone and quartzite make up 70 percent of the formation. About 15 miles south of the report area the exposed part of the Las Vigas Formation of Scott (1939), a probable equivalent of the Yucca, is all sandstone and shale through a thickness of about 2,200 feet (Scott, 1939, pl. 55).

Although no complete section of the formation is exposed, the Yucca must thicken toward the south. It is missing in the Finlay Mountains and on the Diablo Plateau (King and Knight, 1944) but is more than 5,500 feet thick at Quitman Gap (Huffington, 1943, p. 1000) only 15 miles to the south; this distance may have been twice this amount at the time of deposition and prior to thrust faulting.

The following section is here designated as the reference section of the Yucca Formation.

SECTION 6.—*Reference section of the Yucca Formation*

[Northeast side of Yucca Mesa; traverse 6 shown on pl. 1. (Modified from Smith, 1940, p. 623–625)]

	Thickness (feet)
Lower Cretaceous—Bluff Mesa Limestone:	
Limestone, gray, dense, coarsely sandy (in part); weathers buff to gray and has rough surface; contains fragments of pelecypods and gastropods; forms cliffs	128

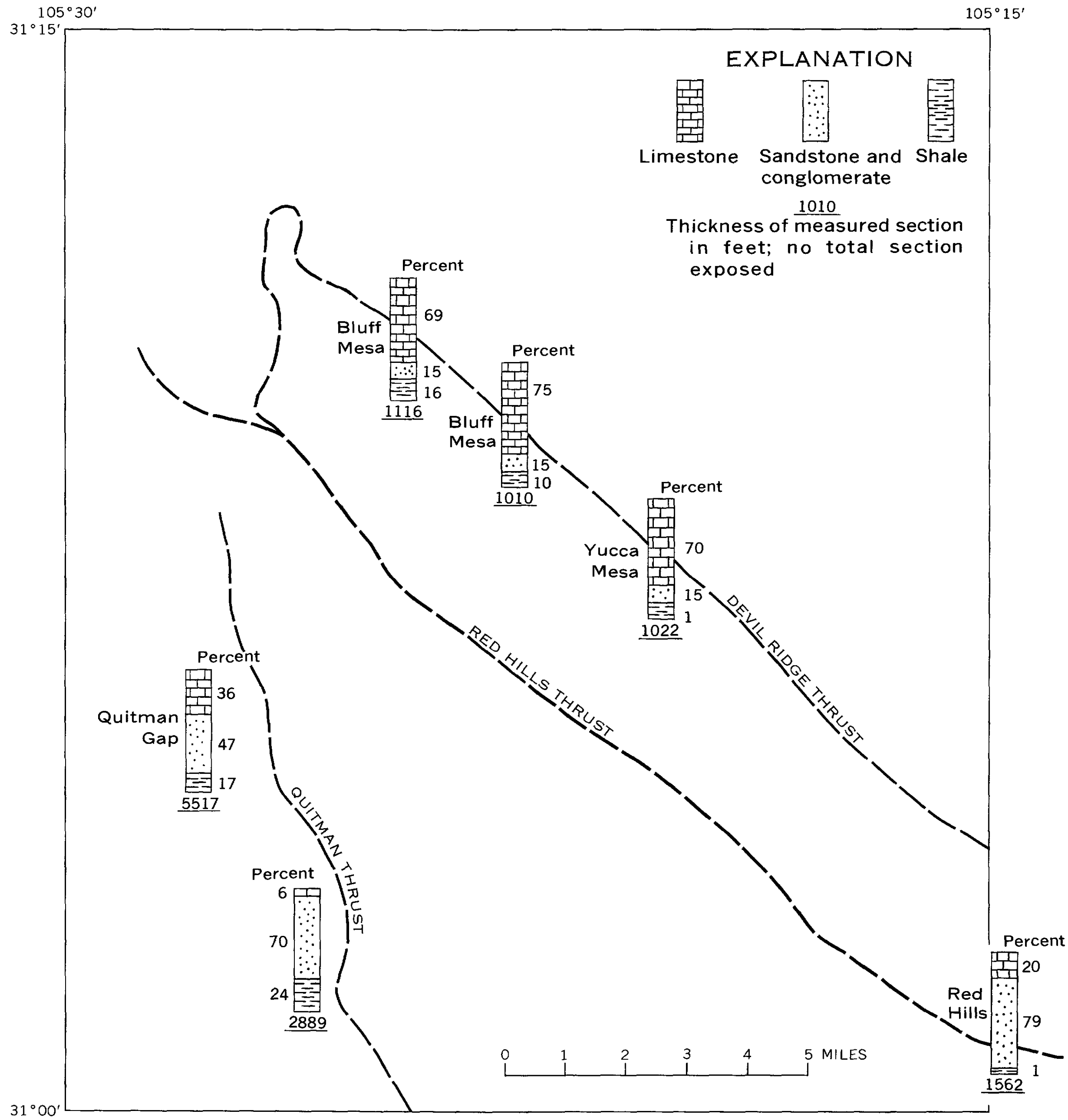

FIGURE 31.—Relative amounts of limestone, sandstone (including quartzite) and conglomerate, and shale and other very fine grained clastic rocks in the Yucca Formation in the Sierra Blanca area.

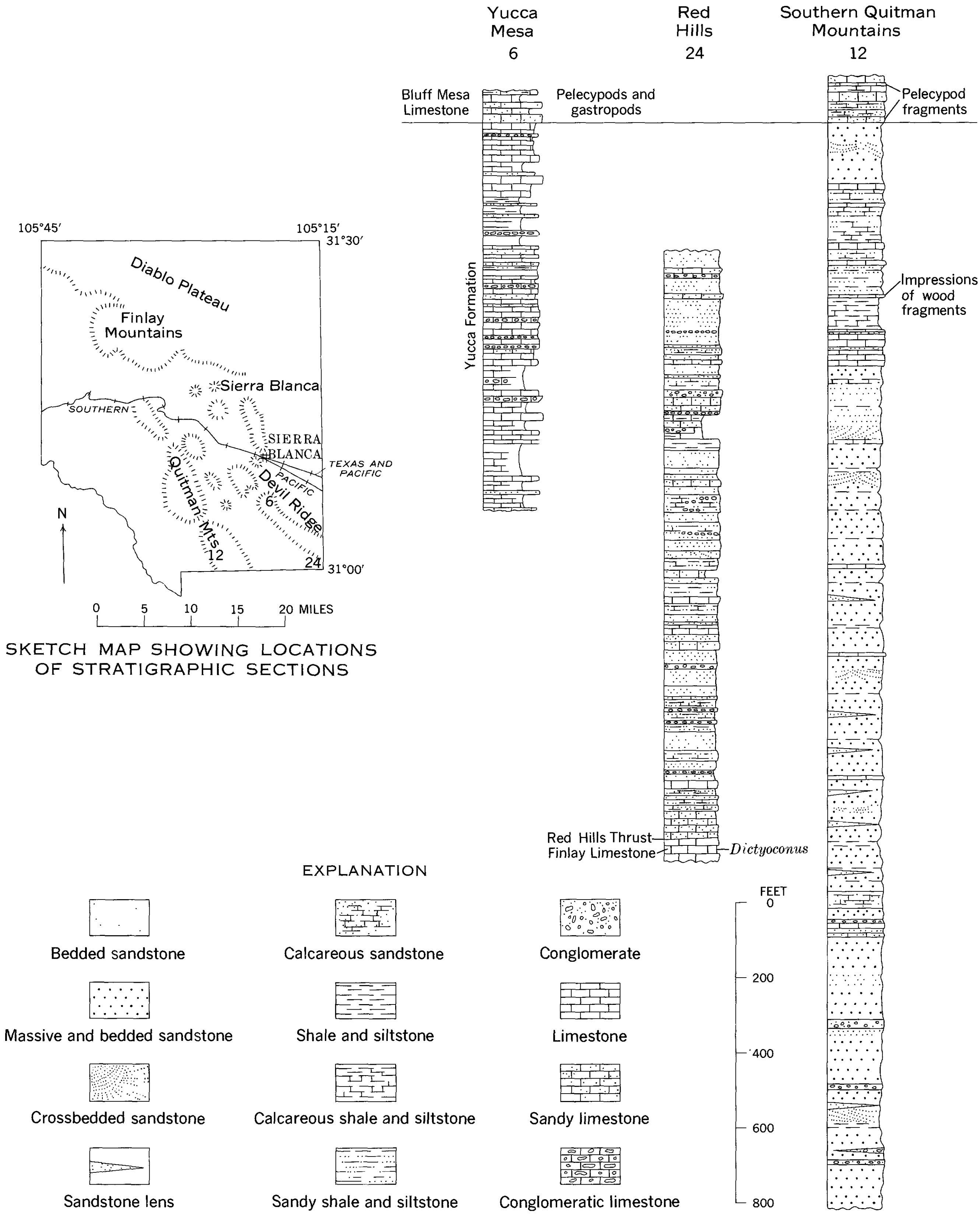

FIGURE 32.—Sections of the Yucca Formation showing decrease in carbonate rocks and increase in fine-grained clastic rocks southwestward across Sierra Blanca area.

SECTION 6.—*Reference section of the Yucca Formation*—Con.

Lower Cretaceous—Yucca Formation:	Thickness (feet)
74. Limestone, thin-bedded; poorly exposed	29
73. Conglomerate of red and gray limestone pebbles; grades downward into red and gray limestone that weathers yellow and salmon red	8
72. Limestone, gray, in thin beds; scattered exposures on debris-covered slope	51
71. Limestone, gray, dense; weathers light creamy gray to yellow; thinly bedded	16
70. Unexposed; probably thin-bedded limestone	28
69. Sandstone, gray, very calcareous, fine-grained; weathers buff to brown	8
68. Limestone, gray, dense; weathers whitish gray to very light brown; nodular in middle and lower parts; forms a low cliff	22
67. Unexposed; probably thin-bedded limestone	37
66. Limestone, gray, dense; weathers light gray and has a nodular surface	2
65. Unexposed; probably red shale	14
64. Quartzite, purple, weathers purple; contains specks of hematite	2
63. Shale, red; poorly exposed	27
62. Sandstone, purple, fine-grained; weathers brownish purple; forms low ledges in places	6
61. Unexposed; thin-bedded limestone in float	38
60. Sandstone, purple, fine-grained, shaly	3
59. Congolmerate of small limestone pebbles, gray; weathers buff to brown	2
58. Unexposed	35
57. Limestone, bright-gray, dense; weathers brown	5
56. Quartzite, white to gray and brown; weathers dark to light brown; some small-scale cross-bedding	4
55. Sandstone, white, medium-grained; weathers white to brown	12
54. Limestone, bright-gray, dense; weathers brown	2
53. Unexposed	20
52. Limestone, bright-gray, dense; weathers brown	1
51. Unexposed	8
50. Limestone, gray, arenaceous; weathers gray	5
49. Sandstone, gray, very calcareous; weathers buff to dark brown	6
48. Unexposed	15
47. Limestone, gray; grades upward into red limestone	6
46. Sandstone, gray, coarse-grained, quartzitic; weathers brownish gray and has thin brown bands that are slightly more resistant and stand out on weathered surface	6
45. Limestone, gray, dense; weathers gray	8
44. Conglomerate of limestone pebbles; grades upward into fairly coarse grained calcareous sandstone that weathers buff to brown; small crystals of hematite in some of the sandstone	4
43. Limestone, red; in places, it is conglomeratic and contains fragments of red and gray limestone	6
42. Conglomerate of limestone pebbles; grades upward into coarse- and fine-grained arenaceous limestone	4
41. Limestone, gray; grades upward into red limestone	15
40. Sandstone, white, medium-grained, quartzitic; weathers brown and has limonite stain	14

SECTION 6.—*Reference section of the Yucca Formation*—Con.

Lower Cretaceous—Yucca Formation—Continued	Thickness (feet)
39. Limestone, gray, very arenaceous, in places gritty; weathers gray	4
38. Unexposed	9
37. Limestone, gray, arenaceous; weathers brownish gray; in places conglomeratic and has limestone pebbles about ¼ in. in diameter	5
36. Limestone, gray, dense; weathers gray	7
35. Limestone, red, dense; weathers red to yellow and brown	16
34. Limestone, gray; weathers light brown to gray	10
33. Limestone, dark-gray, dense; weathers gray; grades upward into conglomerate beds with limestone pebbles ¼ to ½ in. in diameter	8
32. Unexposed; probably thin-bedded limestone	2
31. Limestone, dark-gray, dense; weathers gray	4
30. Unexposed; probably thin-bedded limestone	7
29. Limestone, reddish-gray, dense; weathers dark brown to yellow	5
28. Limestone, gray; weathers buff to brown; poorly exposed	6
27. Limestone, gray, arenaceous; weathers gray to yellow; grades upward into red limestone	4
26. Limestone; poorly exposed	3
25. Limestone, dark-gray, dense; weathers gray to brown	3
24. Conglomerate of limestone pebbles; weathers gray; pebbles average about ½ in. in diameter, some as large as 1 in.; bed more resistant than those beds above and below	3
23. Limestone, gray, dense; weathers gray; and red limestone, weathers yellowish brown	20
22. Conglomerate of limestone pebbles; rounded to subangular pebbles average ½ in. in diameter, but some are as large as 1½ in.; some red limestone pebbles weather yellow; matrix is gray limestone; grades upward into a dense gray limestone that in turn grades into a conglomerate of small angular pebbles	15
21. Limestone, red; weathers yellowish brown	10
20. Limestone, gray, dense; weathers gray	19
19. Limestone, reddish-gray, dense; weathers brown and yellowish brown	14
18. Conglomerate of limestone pebbles as large as 1 in. in diameter, and gray arenaceous limestone; poorly exposed	68
17. Limestone, light-gray, dense; weathers yellow to dark brown	9
16. Limestone, red, dense; weathers buff to pink	3
15. Limestone, gray, dense; grades upward into slightly red limestone at top; upper part conglomeratic; weathers buff to yellow; forms small cliffs	15
14. Limestone, gray, arenaceous in a few thin beds; weathers gray; poorly exposed	33
13. Limestone, red, dense; weathers buff to brown; forms a small ledge	18
12. Unexposed; probably thin-bedded limestone	28
11. Limestone, dark-gray, dense; weathers gray	7
10. Unexposed	16
9. Limestone, red, dense; weathers yellowish brown	8
8. Unexposed	93

SECTION 6.—*Reference section of the Yucca Formation*—Con.

Lower Cretaceous—Yucca Formation—Continued	*Thickness (feet)*
7. Limestone, gray, dense; weathers gray; contains some chert; grades upward into light-red limestone that weathers yellowish brown and then into dense light-gray limestone that weathers yellow	9
6. Unexposed	32
5. Limestone, light reddish-brown, very arenaceous; weathers dark rusty brown	3
4. Conglomerate of limestone pebbles, gray; weathers gray; pebbles 1/4 to 1 in. in diameter	2
3. Limestone, gray, dense, gray-weathering, and dense red limestone weathering yellowish brown	20
2. Limestone, thin-bedded; poorly exposed	13
1. Limestone, gray, dense; weathers gray; in part conglomeratic with limestone pebbles 1/4 to 3/4 in. in diameter; base not exposed	2
Total measured thickness	1, 022

BLUFF MESA-YUCCA MESA-DEVIL RIDGE AREA

(DEVIL RIDGE THRUST BLOCK)

The thickest sequences of Yucca Formation in this area are in Yucca and Bluff Mesas, where limestone and limestone conglomerate constitute 70 to 75 percent of the formation, shale 10 to 16 percent, and sandstone and conglomerate about 15 percent.

The limestone is mostly reddish brown or yellowish brown, although some beds are gray. Textures are fine to coarse; many of the coarser varieties are clastic. Some of the denser beds are magnesian or dolomitic; a pinkish-gray magnesian limestone in the lower part of the formation on the north side of Yucca Mesa contains 86.66 percent $CaCO_3$, 2.32 percent $MgCO_3$, and 8.66 percent acid insoluble material (analysts: E. C. Mallory and D. L. Skinner, U.S. Geol. Survey).

Conglomerate beds consist of pebbles that average about one-half inch and range from 1/8 to 1 1/2 inches in diameter. Most are well rounded, but sharply angular particles make up some thin beds. The pebbles are chiefly dense gray limestone, but in places a few are red limestone and dark chert. The matrix is limestone, commonly sandy. Most of the conglomerate beds are 2 to 4 feet thick, and pebbles are scattered through other rocks through thicknesses of as much as 20 feet.

Red and purple shale and siltstone, mostly calcareous and partly sandy, are characteristic of the formation and occur in beds 2 inches to 3 feet thick.

Sandstone, quartzitic sandstone, and quartzite constitute only a small part of the formation in this area. They are fine to coarse grained and light to dark brown, except for thin beds of purple and green quartzite on Yucca Mesa. They consist mainly of subangular to rounded quartz grains in a calcareous or siliceous cement. Beds are generally from 1 to 3 feet thick and are mostly evenly laminated; some beds are cross-laminated.

RED HILLS AND OTHER PARTS OF RED HILLS THRUST BLOCK

In the Red Hills thrust block the Yucca crops out in the Red Hills, along a ridge southwest of Devil Ridge, and around Zimpleman Pass in the northern Quitman Mountains. The strata in the Quitman Mountains have been metamorphosed, chiefly to lime-silicate rocks.

About 1,600 feet of the formation is exposed in the Red Hills thrust block. Limestone makes up 20 percent; sandstone, quartzite, and siliceous-pebble conglomerate, 79 percent; and shale, 1 percent.

The sandstone and quartzite are fine to coarse grained, are variously brown, red, gray, and white and weather to shades of brown. They generally consist of well-sorted subangular to well-rounded quartz grains and include accessory grains of chert and dark minerals. The sandstone is cemented by calcite, the quartzite by silica. Beds are mostly 1 to 5 feet thick, but a few are as much as 20 feet thick; some layers are crossbedded.

In contrast to the Devil Ridge thrust block to the north, siliceous conglomerate is abundant in the Red Hills thrust block. The conglomerate is in beds and lenses, is variously white, gray, or brown on fresh surfaces, and weathers brown. Most beds contain only quartz or chert pebbles, but some contain both, and others contain limestone pebbles also.

In the quartz-pebble conglomerate, the fragments average one-half inch in diameter and are subangular to well rounded. The pebbles are mostly white or red vein quartz and are in a sandstone matrix that is slightly calcareous in places. The conglomerate beds are typically 5 feet thick, but some are as much as 20 feet thick.

The chert conglomerates are coarser and contain pebbles generally 1 to 2 inches and as much as 3 1/2 inches in diameter. The pebbles are chiefly of gray, brown-weathering chert and are set in a coarse sandy matrix, in part cross-laminated. Most of the chert conglomerates form discontinuous lenses, rarely more than 100 feet across and 10 feet thick, some of which fill channels cut in the underlying beds. The channel fills are small, typically about 25 feet wide and less than 10 feet thick.

The limestone is gray or reddish brown and weathers to shades of gray, red, and yellow. It is variously dense, sandy, shaly, or nodular and forms beds 1 to 5 feet thick.

Adjacent to the Quitman pluton, the sedimentary rocks have been metamorphosed in a zone a few feet to several hundred feet wide. Alteration has been most intense adjacent to the stock at the north end of the pluton, particularly along its west side.

In the vicinity of Zimpleman Pass, limestone of the Yucca Formation has been largely altered to a dark silicate rock with abundant brown and green garnet and accessory actinolite, epidote, plagioclase, jasper, and idocrase. Some sulfide minerals and specular hematite also occur, particularly where later fissures cut the rocks. White beds of almost pure wollastonite and beds that contain scapolite and tremolite occur along the outer border of the silicate zone. Farther away from the pluton, some of the limestone is altered to white coarsely crystalline marble. The shaly beds in the zone of metamorphosed rock have been altered to hornfels.

SOUTHERN PART OF QUITMAN MOUNTAINS (QUITMAN THRUST BLOCK)

In the southern part of the Quitman Mountains, sandstone and quartzite make up 47 to 70 percent of the Yucca Formation. Shale constitutes 17 to 24 percent, and limestone, 6 to 36 percent. The limestone increases northward, and the sandstone southward.

The sandstone and quartzite beds are gray, green, pink, red, or maroon and weather to shades of the same colors. In the Quitman Gap area, where they make up nearly half of a sequence more than a mile thick, the sandy rocks are concentrated in the middle part of the formation. They are fine to coarse grained, and the coarser beds commonly contain lentils of tiny pebbles. The quartz grains, the chief constituents, are subangular to well rounded, are well sorted in many beds, and are cemented by lime or silica. Some layers contain calcareous nodules and small impressions of wood. The sandstone and quartzite occur in beds generally ½ to 3 feet thick, although a few beds are as thick as 5 feet. Some of the beds are laminated, and some show graded bedding. The beds of sandstone are commonly lenticular and locally grade into shale.

The limestones are unusually varied. They are gray and greenish gray to brown, have intermediate yellow, pink, and red hues, and form 1- to 3-foot beds which are massive, shaly or platy, fine grained to coarse grained, and sandy. Some are full of calcareous nodules 2 to 3 inches across. Stratification is generally even and parallel, but many beds occur as lenses 8 to 12 inches thick and 3 to 10 feet across. Some of the beds are magnesian or dolomitic; a fine-textured sandy dolomitic limestone from the southern part of the mountains contains 51.19 percent $CaCO_3$, 7.14 percent $MgCO_3$, and 31.40 percent of acid-insoluble material (analysts: E. C. Mallory and D. L. Skinner, U.S. Geol. Survey).

The shales are pink, maroon, green, gray, yellow, purple, or red and consist of silt and clay particles, mixed in some units and segregated as alternating platy siltstone and claystone in others; some are calcareous. The shales form units 3 inches to 3 feet thick.

Lentils of calcareous or siliceous conglomerate no more than a few inches thick occur in some of the limestone beds. The siliceous pebbles are quartz, quartzite, and gray or red chert and are as much as 2 inches in diameter; limestone pebbles are as much as half an inch in diameter.

THICKNESS

Although no complete section of the Yucca Formation is exposed in the Sierra Blanca area, the thickness obviously increases southward. On the north side of Bluff Mesa a section, 1,116 feet thick, is exposed (Huffington, 1943, p. 999 and 1018), and although the base is not visible, probably no more than 200 or 300 feet is covered by the alluvium west of Bluff Mesa. In the Red Hills, 1,562 feet is exposed, and neither the top nor the base of the formation is visible. At Quitman Gap, 5,517 feet is exposed, and the base is not visible (Huffington, 1943, p. 999 and 1016). In this strongly deformed area, the beds are overturned, but there is no evidence that they are repeated. In the lower southwestern part of the exposed section, fracture cleavage in a limestone bed and oscillation ripple marks both indicate that the beds are overturned. In the sandy and quartzitic middle part of the section, at least 25 sets of crossbeds show overturned bedding.

The Yucca Formation is absent north of the Devil Ridge thrust. The Campagrande Formation, equivalent to the Bluff Mesa Limestone, which overlies the Yucca, rests directly on Permian rocks in the Finlay Mountains.

RELATION TO ETHOLEN CONGLOMERATE AND TORCER FORMATION

Beds classified as Yucca overlie the Etholen Conglomerate on the southwestern part of Etholen Hill. The basal strata of the Yucca here are lithologically similar to those of the nearby reference locality, being gray limestone with algal structures 1 to 1½ inches in diameter. Bedding is obscure, and the strata are gently folded, but the contact with the Etholen seems to be conformable.

The Yucca overlies the Torcer Formation on the west side of Zimpleman Pass in the northern Quitman Mountains. Although the rocks are metamorphosed and exposures are poor, the formations appear to be conformable.

This conformity of the Yucca with both the Etholen and Torcer is observable in such small areas that the regional relations of the three formations remain uncertain. It is possible, for example, that the lower beds in the Yucca Formation interfinger with the upper beds of the other two formations.

AGE AND CORRELATION

Numerous fossil fragments have been found in the Yucca Formation, but none are useful in establishing its exact age. Adkins (1932, p. 296) recorded *Arca*, *Ostrea*, and caprinids in the formation, but we did not find them.

On the basis of its stratigraphic position below the Bluff Mesa Limestone of definite Glen Rose age, the Yucca Formation evidently is low in the Cretaceous sequence. Lack of precise data from fossils prevents a more precise assignment than Early Cretaceous.

CONDITIONS OF DEPOSITION

The Mesozoic sea that entered the area from the south during Jurassic time continued its advance during Yucca time. While the sea spread, the Mexican geosyncline sank and received a wedge of sediment that thickened southward. The shoreline lay near the present south edge of the Diablo Plateau and extended eastward beyond Eagle Spring (about 10 miles east of the southeast corner of the Sierra Blanca area), where the Yucca is a little more than 300 feet thick (Smith, 1941).

The sediments making up the Yucca Formation were all deposited in shallow water as indicated by the common occurrence of rippled and cross-laminated sand. Thus deposition presumably kept pace with the sinking of the basin.

The lithologic change from north to south poses problems we are unable to solve. The quartzose sandstone facies of the Yucca is farther removed from shore than the carbonate facies. Most of the limestone itself is a clastic rock, and the conglomerate beds are most conspicuous near the ancient shore, but the source for the great thickness of sandstone in the south remains unknown.

All features indicate that the area was one of considerable relief during deposition of all the strata between the base of the Malone Formation and the top of the Yucca Formation. The low areas were flooded first and filled with sand, and as the relief of the sea floor decreased, limy muds were deposited in increasing amounts. Limestone pebbles that escaped pulverization in the surf were occasionally washed out from shore and interbedded with the calcareous mud. Although probably deposited in a lower energy environment, the limestone conglomerate of the Yucca may have been deposited under conditions similar to those under which the conglomerate of the Etholen was deposited.

BLUFF MESA LIMESTONE

DEFINITION

The term "Bluff Bed" was used by Taff (1891, p. 727) for the predominantly gray limestones exposed on Bluff Mesa, but as the name Bluff is preoccupied, the formation is now termed the Bluff Mesa Limestone. Farther south, at Quitman Gap, Taff distinguished a Bluff Bed and a Quitman Bed above his Mountain Bed, or Yucca Formation; because most of the Quitman Bed is likewise equivalent to the Bluff Mesa Limestone of the type area, this term was abandoned. In the Quitman Mountains to the south of the Sierra Blanca area, Scott (1939, p. 973) placed the Cuchillo and Glen Rose Formations above the Las Vigas Formation. The Bluff Mesa Limestone is probably equivalent to the Cuchillo and to at least part of Scott's Glen Rose, the upper part of which probably also includes beds equivalent to the Cox Sandstone, which overlies the Bluff Mesa Limestone.

Within the Sierra Blanca area the Bluff Mesa Limestone is used only in the area south of the Devil Ridge thrust; north of the thrust the name Campagrande Formation is used for equivalent but somewhat different strata.

The Bluff Mesa Limestone is exposed chiefly in the southeast quarter of the report area, where it caps Bluff and Yucca Mesas and is prominent on Bug Hill, Double Hill, and some of the low hills northeast of Devil Ridge. It forms a high ridge in the southern part of the Quitman Mountains and a narrow band along the west side of the northern part of the Quitman Mountains. A few outlying exposures occur in the Hueco Bolson and Rio Grande Valley.

The formation characteristically consists of massive limestone beds that crop out in prominent ridges, cliffs, and ledges. Between the ledges and bluffs, thinner beds of limestone and shale underlie gentler slopes.

LITHOLOGY

The Bluff Mesa Limestone is a fairly uniform body of limestone, containing minor amounts of sandstone and shale (pls. 3 and 4). Most beds are lenticular and cannot be traced more than a few hundred feet. Much of the limestone is very fossiliferous.

The formation ranges in thickness from 1,080 feet on Devil Ridge about 3 miles southeast of Yucca Mesa to 1,473 feet on Yucca Mesa. It is 1,211 feet thick near the southeast end of Devil Ridge and 1,201 feet at the southernmost exposures in the Quitman Mountains.

The following stratigraphic section measured on Bluff Mesa is here designated the reference section. The thickness of 1,445 feet probably is close to the total at this locality, for although the uppermost beds are concealed, the missing part probably amounts to no more than a few tens of feet.

SECTION 13.—*Reference section of the Bluff Mesa Limestone*

[Bluff Mesa; traverse 13 shown on pl. 1. Fossil identifications by J. Fred Smith, Jr.]

	Thickness (feet)
Lower Cretaceous—Bluff Mesa Limestone:	
Top not exposed; probably near top of formation.	
26. Limestone, gray, slightly sandy, in thin beds	178
25. Unexposed; probably thin beds of sandy limestone and shale	80
24. Limestone, gray, sandy, mostly in thin beds	303
23. Quartzite, brown, fine-grained	14
22. Limestone, gray, in thin beds; many *Orbitolina* (probably *O. minuta* Douglass; Douglass, 1960, p. 36–39, pl. 16)	37
21. Limestone, black, in thin beds; poorly exposed	26
20. Chiefly unexposed; thin shaly beds	109
19. Limestone, gray; very fossiliferous—abundant *Exogyra* sp., *Gryphaea* sp., and corals	15
18. Limestone, gray; reeflike masses of corals	8
17. Limestone, gray, sandy; weathers gray	69
16. Limestone, gray, very sandy, in thin beds; some brown sandstone	65
15. Sandstone, brown, calcareous; fossil fragments	2
14. Limestone, gray, sandy, thin- to thick-bedded; weathers gray; very fossiliferous—many shell fragments are seen in cross section in the rock	71
13. Limestone, gray, sandy, thin-bedded; many *Exogyra* sp., *Gryphaea* sp., and corals which are seen as cross sections in the rock	64
12. Limestone, gray, coarsely sandy	34
11. Limestone, gray, sandy, thin-bedded; poorly exposed	52
10. Limestone, gray, sandy; weathers gray; some fossil fragments	23
9. Limestone, gray, sandy, thin-bedded; poorly exposed	27
8. Limestone, gray, sandy; weathers gray; contains some fossil fragments	26
7. Sandstone, gray, coarse-grained, calcareous, thin-bedded, and sandy limestone	64
6. Limestone, gray, fragmental, sandy, and calcareous sandstone; weathers gray	8
5. Limestone, gray, sandy; many *Orbitolina texana* (Roemer); forms cliff	31
4. Limestone, gray, sandy; weathers gray	23
3. Sandstone, gray, coarse-grained, calcareous; weathers gray	11
2. Limestone, gray, slightly sandy; weathers gray; fossiliferous—abundant *Exogyra* sp. and *Gryphaea* sp.; forms cliff	36
1. Limestone, gray, slightly sandy, in thin beds; some interbeds of brown sandstone	69
Total measured thickness	1,445

SECTION 13.—*Reference section of the Bluff Mesa Limestone*—Continued

Lower Cretaceous—Yucca Formation:
Limestone, gray, weathering yellow; poorly exposed at contact with Bluff Mesa Limestone.

Sandy limestone makes up the greater part of the formation. Most beds are gray, but the more sandy parts are brown and greenish gray. Nearly all the limestone is fragmental and is made up of broken shells intermingled with sand. Most of the sand is coarse, though it ranges from fine to coarse; the coarsest grains are of clear quartz and are a sixteenth of an inch in diameter.

The sandy limestones occur mostly in 1- to 3-foot beds but also in very thin beds and in some as much as 30 feet thick. Internally, the beds are massive or laminated, and many are cross-laminated. Single beds thin and pinch out within a few feet or a few hundred feet, but units of similar lithology are traceable for several miles.

Pure limestone containing little or no quartz sand is much less common. Some of the less sandy limestone contains abundant calcareous nodules 4 to 5 inches long. Other limestones are interbedded with yellow or gray and commonly sandy shale which is in partings a fraction of an inch thick or in layers 2 to 3 feet thick. Most of the pure limestone consists of megascopic and microscopic shell fragments, including whole and broken tests of the giant foraminifers *Orbitolina texana* (Roemer) and *O. minuta* Douglass, which in places form layers 1 to 3 feet thick. Near the middle of the formation are some layers of gray oolitic limestone. The denser limestones are commonly marked by stylolites. Masses of closely packed corals occur near the crest of Bluff Mesa, where they weather in relief; the largest mass observed is 29 feet across.

Sandstone and quartzite occur in lenses 2 to 3 feet thick, each traceable several hundreds of feet to pinchouts or to gradations into sandy limestone. They are brown, white, tan, gray, or green and generally weather brown. Almost all the grains are quartz, but a dark accessory mineral, probably magnetite, is also present; grains range from very fine to coarse and pebbly and are set in both calcareous and siliceous cements. Ferruginous concretions about 1 inch in diameter are scattered through some of the beds. Crossbedding is common, especially in thin layers of very fine grained green quartzite.

RELATION TO YUCCA FORMATION

The Bluff Mesa Limestone lies conformably over the Yucca Formation but has a distinct and easily recognized contact along Devil Ridge and northwestward. Thin beds of limestone and shale in the

Yucca Formation give place to massive beds of gray sandy limestone in the Bluff Mesa Limestone.

In the southern part of the Quitman Mountains a transition zone of interbedded limestone and sandstone several hundred feet thick intervenes between the main bodies of the two formations (Huffington, 1943, p. 1001). The base of the Bluff Mesa is arbitrarily placed in this zone at the base of the lowest fossiliferous bed, although the bed is not everywhere at exactly the same stratigraphic level. Even so, the contact probably does not differ vertically from place to place by more than 50 feet.

FOSSILS

Fossils are abundant in the Bluff Mesa Limestone, although many are fragmental and others are difficult to extract from the rock. The most abundant forms in certain layers are *Orbitolina* and *Exogyra quitmanensis* Cragin (fig. 33).

The large oyster *Exogyra quitmanensis* Cragin occurs between 180 and 370 feet above the base of the formation in the southern part of the Quitman Mountains and makes up whole beds between 210 and 215 feet. Strata containing this fossil also crop out directly south of the road through Quitman Gap,

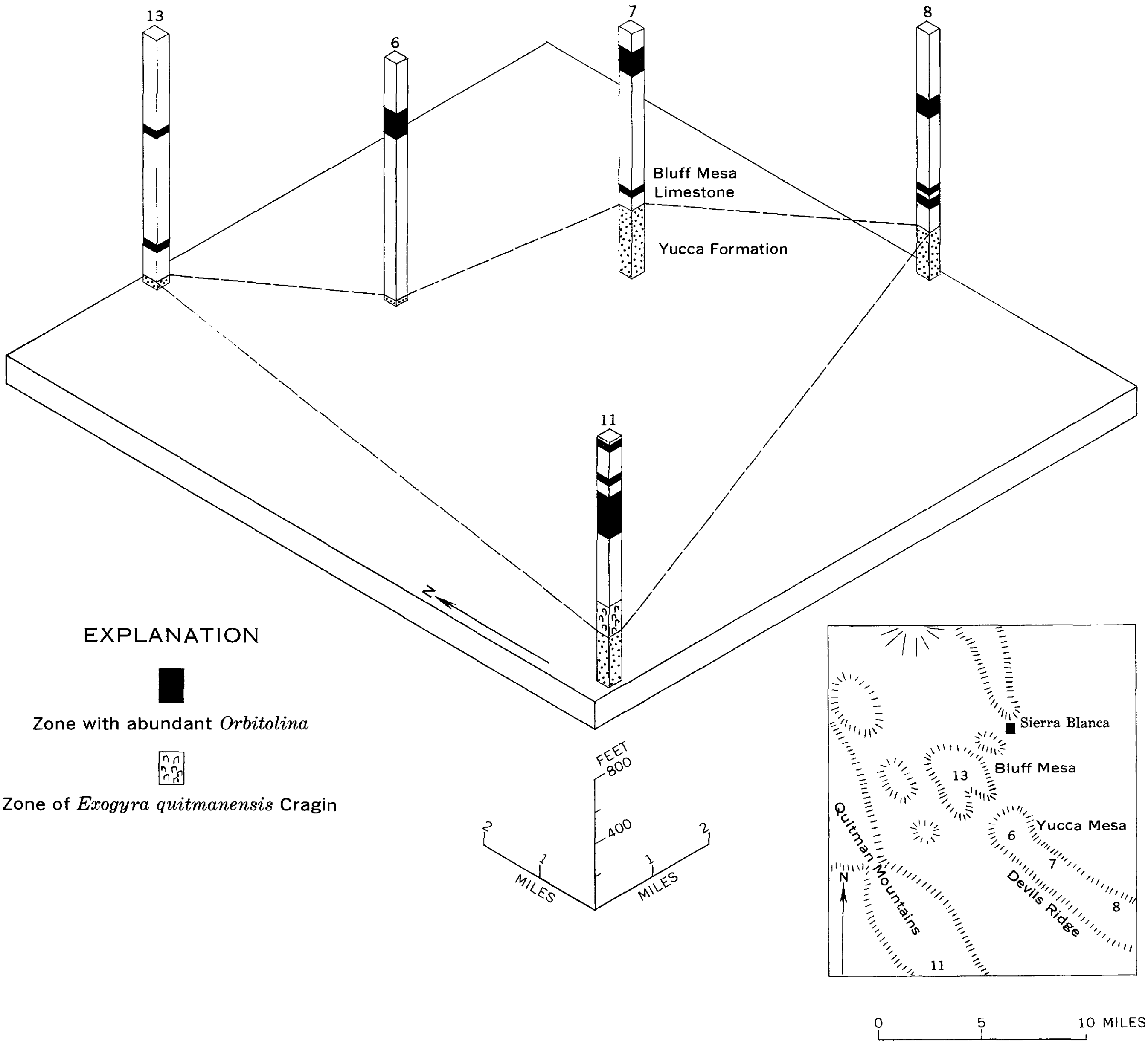

FIGURE 33.—Isometric diagram showing conspicuous zones of *Orbitolina* and *Exogyra quitmanensis* Cragin in five measured stratigraphic sections of the Bluff Mesa Limestone.

near the east limit of exposure of the formation. The most fossiliferous beds are not persistent laterally. *Exogyra quitmanensis* Cragin has not been observed in the Bluff Mesa Limestone at its reference locality or in any of its other exposures northeast of the Quitman thrust.

Orbitolina occur in the same areas as *Exogyra quitmanensis* Cragin but have a broader geographic range toward the north and northeast. These foraminifers are abundant at certain horizons in the Quitman Mountains, in Devil Ridge, and in some of the hills rising from the Hueco Bolson. In the southern Quitman Mountains, they are most abundant from 680 to 965 feet and from 1,125 to 1,160 feet above the base of the formation and thus extend much higher stratigraphically than *Exogyra quitmanensis* Cragin. From Bluff Mesa through Devil Ridge the foraminifers are concentrated at two levels in the formation, one near the base and one in the upper half. The lower level is generally between 85 and 260 feet above the base and the upper between 700 and 1,050 feet. The tests are not distributed uniformly at either level but are concentrated in patches. While we were studying the area, all *Orbitolina* were referred to one species, *O. texana* (Roemer). Since then, however, Douglass (1960, p. 36-39) has named a new species, *O. minuta* Douglass, and reported that *O. texana* occurs in the lower part of the Glen Rose Limestone and *O. minuta* in the upper part. In the Sierra Blanca area, the lower zone in the Bluff Mesa Limestone contains *O. texana* (Roemer), and the upper zone contains *O. minuta* Douglass (Douglass, 1960, pl. 16).

Requienia and other rudistid pelecypods form lenses in parts of the formation, but their taxonomy and stratigraphic ranges remain to be studied.

Of the following fossils identified from the Bluff Mesa, most were collected from the upper interval of abundant *Orbitolina* along Devil Ridge (Smith, 1940, p. 610-611): *Orbitolina texana* (Roemer), *Haplostiche texana* Conrad, *Anomalina* sp., *Porocystis globularis* (Roemer), *Heteraster obliquatus* (Clark), *Diplopodia? taffi* Cragin, *Cyprimerica* sp., *Exogyra texana* Roemer, *Exogyra* sp., *Protocardia* cf. *P. texana* (Conrad), *Protocardia* cf. *P. stonei* Cragin, *Pecten* sp., *Ostrea* sp., *Artica* cf. *A. roemeri* (Cragin), *Artica* sp., *Isocardia? medialis* (Conrad), *Isocardia?* sp., *Cardium?* sp., *Pholadomya knowltoni* Hill, *Pholadomya* sp., *Homomya?* sp., *Cucullaea* (*Idonearca*)? *terminalis* Conrad, *Cucullaea?* sp., *Modiola branneri* Hill, *Trigonia* cf. T. *stolleyi* Cragin, *Trigonia* sp., *Tapes* sp., *Tapes?* sp., *Requienia* sp., *Anatina* sp., *Nerinea incisa* (Giebel), *Nerinea* sp., *Lunatia? pedernalis* Hill (not Roemer), *Natica? pedernalis* Roemer, *Natica?* sp., *Amauropsis?* cf. A. *pecosensis* Adkins, and *Tylostoma?* sp.

AGE AND CORRELATION

The Bluff Mesa Limestone contains virtually the same fauna as the Glen Rose Limestone of the Trinity Group (Lower Cretaceous) in central Texas. *Orbitolina texana* (Roemer) and *O. minuta* Douglass (Douglass, 1960, p. 38), in particular, are characteristic of both formations.

The Bluff Mesa Limestone is probably also equivalent to the very thick Lower Cretaceous rocks in the Little Hatchet Mountains of southwestern New Mexico (Lasky, 1938 and 1947, p. 16–26) and to the Mural Limestone of southeastern Arizona (Stoyanow, 1949, p. 20), which contain similar fossils.

CONDITIONS OF DEPOSITION

The foraminifers, echinoids, and stony corals of the Bluff Mesa Limestone suggest that this limestone was deposited in a warm clear shallow sea of normal salinity, overlying bottoms that were firm and well aerated. Brisk circulation is indicated by the cross-lamination, the local occurrences of oolites, the generally clastic nature of the limestone, the coral biostromes, and the abundant large sessile pelecypods.

Variations in the thickness of the formation along Devil Ridge and to the northwest suggest that the floor of the sea had some hollows and prominences. There must have been, however, less relief than during the deposition of the Torcer, Etholen, and Yucca sediments, as the Bluff Mesa is more homogeneous and less variable in thickness than these older formations. To a certain extent this homogeneity is contrived, however, because we have assigned the less homogeneous littoral and near-shore equivalents of the Bluff Mesa Limestone to another formation, the Campagrande Formation of the southern part of the Diablo Plateau.

CAMPAGRANDE FORMATION

DEFINITION

The Campagrande Formation was named by Richardson (1904, p. 47) for Campo Grande Arroyo, which drains from the Finlay Mountains into the Rio Grande. This arroyo has several head branches, and Richardson did not state specifically which one was the type locality. He did state, however, that the formation was 375 feet thick, and this thickness agrees with that of the outcrops along the principal branch leading past the Wilkie Ranch house.

In defining the Campagrande, Richardson evidently intended that it include all the Cretaceous strata beneath the quartzose rocks of the Cox Sandstone in the

Diablo Plateau area. So defined, it is a heterogeneous deposit with at least three lithologic facies. To the northwest, the Campagrande consists principally of limestone conglomerate and some interbedded sandstone. In the area of the Finlay Mountains, marl, shale, siltstone, and sandstone dominate. Farther eastward along a broad belt extending from Sierra Blanca town to the Sierra Prieta (fig. 34), limestone is the principal rock. East of Sierra Blanca town along the southern foothills of the Diablo Plateau, all three of these facies are complexly intermingled.

In the eastern part of the Finlay Mountains, the Campagrande crops out at the center of a structural dome, and in the western part its outcrop encircles a similar but more deeply eroded uplift. The formation is concealed by younger deposits in all directions away from its type area, but it reappears on Triple Hill, 9 miles to the southeast, along the border of an intrusive mass of igneous rock. Farther eastward, it is preserved as remnant benches and mesas, and originally it must have extended nearly to the east boundary of Hudspeth County. In the northern part of the county the formation has been reported in the Sierra Prieta and Cerro Diablo and along the east flank of the Hueco Mountains (fig. 34).

The formation ranges in thickness from 375 to 800 feet. Between the Sierra Prieta and the Finlay Mountains, it thickens southwestward at a rate of about 10 feet to the mile, and in the western part of the Finlay Mountains, at about 200 feet to the mile. East of Sierra Blanca town, the southwestward thickening is about 25 to 30 feet to the mile.

FINLAY MOUNTAINS AREA

A full section of the Campagrande Formation is exposed in the western part of the Finlay Mountains where the formation is 375 to 400 feet thick at the north and about 800 feet thick at the south. In the eastern part of the mountains only 242 feet in the upper half of the formation is exposed. Lithology of the formation is variable, especially in the lower part, which consists of interbedded limestone, siltstone, sandy shale, sandstone, and conglomerate (pl. 5). The upper 200 feet or so of the formation is limestone and marl in alternating layers. As exposed in the western part of the mountains, the Campagrande is 30 percent limestone, 27 percent siltstone and sandy shale, 18 percent marl, 15 percent standstone, and 10 percent conglomerate. The exposed upper part in the eastern Finlay Mountains is 64 percent marl and 36 percent limestone.

The following measured stratigraphic sections indicate the character of the Campagrande Formation in the Finlay Mountains. The first section is designated the reference section for the formation.

SECTION 1.—*Reference section of the Campagrande Formation*

[West side of the western part of the Finlay Mountains; traverse 1 shown on pl. 1]

	Thickness (feet)
Lower Cretaceous—Cox Sandstone:	
Shale, gray and brown.	
Lower Cretaceous—Campagrande Formation:	
36. Limestone, gray, fine-textured, in layers a foot or less thick, containing minute cubes of hematite (after pyrite); small turritelliform gastropods (*Nerinea*) abundant in upper beds. A sill of hornblende porphyry 13 ft thick separates this unit from overlying Cox Sandstone	12
35. Limestone and marl, gray, in an alternating thinly bedded sequence that is approximately 35 percent limestone and 65 percent marl. Marl beds weakly indurated and poorly exposed; in units as much as 11.5 ft thick; commonly mixed with fine and very fine quartz sand in amounts around 10 percent; contains shell fragments, foraminifers, and ostracodes in many layers. Limestone mostly hard and well exposed; in layers between 0.5 and 2 ft thick; fine textured; many beds fossiliferous (*Porocystis* in upper 32 ft)	179
34. Limestone, dark-gray, fine-textured, containing small turritelliform gastropods and *Porocystis*? Caps cuesta. Locally, a sill of hornblende porphyry 8 ft thick follows along the base of this unit	9.0
33. Marl, dark-gray; emits fetid odor when broken; contains abundant foraminifers, ostracodes, echinoid spines, and fragments of shells and bryozoan colonies	7
32. Limestone, dark-gray, very fossiliferous; some of middle and upper beds made almost entirely of rudistids, and some of the lower beds of stony corals (*Stephanocoenia*) and *Porocystis*. Also contains abundant echinoid spines, bryozoa, ostracodes, and a variety of small foraminifers. Forms cliff	21
31. Sandstone, gray, brown-weathering, and arenaceous limestone	5
30. Limestone, dark-gray, arenaceous; contains shell fragments	3.5
29. Shale, gray, sandy; poorly exposed	11.0
28. Limestone, dark-gray arenaceous	1.5
27. Silt and sand, buff	3.0
26. Limestone, medium-gray, oolitic; weathers light olive gray; breaks irregularly and crumbly. Contains rounded granules of dark-gray limestone and pebbles of chert, especially at base where there are lentils of chert pebble conglomerate. Rock laminated and crossbedded on a small scale. Sill of hornblende porphyry 2.5 ft thick; locally follows base of unit	24.0
25. Limestone, dark-gray, fine-textured	1.5
24. Silt and fine sand, gray	15
23. Limestone, dark-gray, fine-textured; contains lentils of pebble and cobble conglomerate	12.0
22. Silt, gray, and fine sand; poorly exposed	10.0
21. Conglomerate of chert and limestone pebbles	1.5

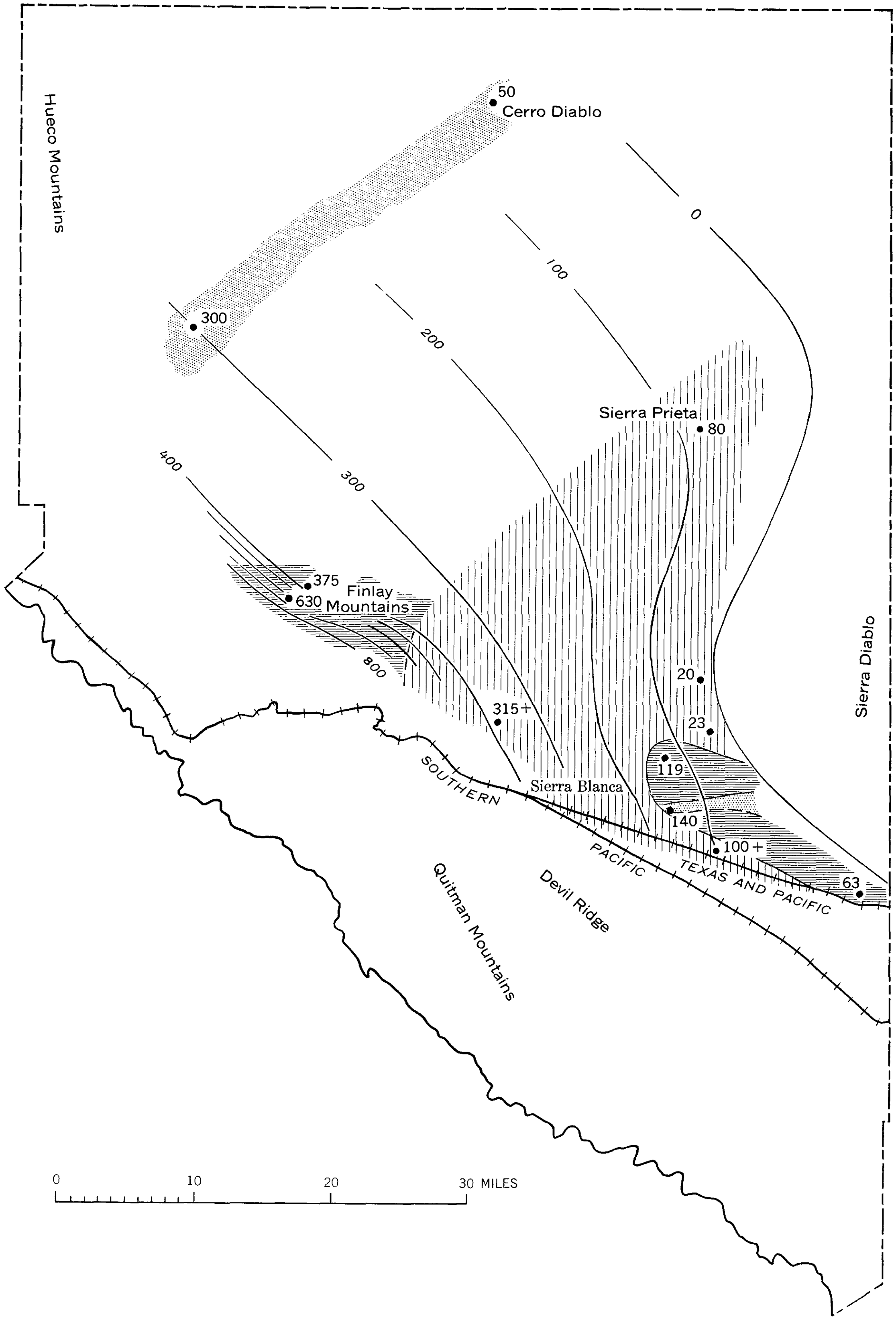

FIGURE 34.—Variations in thickness and lithology of Campagrande Formation in Hudspeth County, Tex. Isopach lines at intervals of 100 feet show thickening of formation toward southwest. Upright figures give thickness in feet at localities where sections have been measured. Stippled pattern indicates section dominantly of conglomerate or sandstone. Closely spaced horizontal lines indicate section dominantly of fine-grained clastic rocks (clastic ratio 1.06 to 9.50; sand-shale ratio 0.18 to 0.53). Widely spaced vertical lines indicate section dominantly of limestone (clastic ratio as much as 0.74; sand-shale ratio as much as 0.50).

SECTION 1.—*Reference section of the Campagrande Formation*—Con.

Lower Cretaceous—Campagrande Formation—Continued	*Thickness (feet)*
20. Silt and sand, gray, having partings of nodular gray limestone and gray calcareous sandstone; poorly exposed	46
19. Conglomerate of well-rounded pebbles of limestone and chert; forms small bluff	16
18. Silt, gray, grading downward into yellowish-brown silt	25
17. Silt, gray; fine sand and interbedded nodular gray limestone	7
16. Limestone, dark-gray, consisting of closely packed algal pebbles as much as 4 cm across; calcite fills interstices	2
15. Unexposed	38.0
14. Conglomerate of limestone and chert pebbles and cobbles, all set in sandy matrix; local partings of sandstone	7
13. Silt and sand weathering to shades of gray and yellowish brown; poorly exposed	6.0
12. Limestone, light-gray, fine-textured; locally rests on sill of hornblende porphyry 4 ft thick	15
11. Limestone, nodular, gray fossiliferous; interbedded gray silt and sand	13.0
10. Limestone, gray, fine-textured, nodular	10
9. Unexposed	13.0
8. Limestone conglomerate, coarse; scattered chert pebbles; boulder conglomerate at base grades upward into pebble and cobble conglomerate	7
7. Silt, gray, and fine sand	16
6. Limestone pebble conglomerate; scattered well-rounded chert pebbles; matrix sandy. Locally rests on sill of hornblende porphyry 10 ft thick	1.0
5. Limestone, dark-gray, fine-textured	2
4. Silt, gray and maroon, and fine sand	50.0
3. Sand, gray and maroon, fine, and interbedded gray, tan-weathering arenaceous limestone; poorly exposed	20.0
2. Conglomerate of pebbles, cobbles and boulders of limestone and chert; poorly exposed	20.0
Total measured thickness	630
Unconformity.	
Permian—Leonard Series (undivided):	
1. Limestone pebble conglomerate, gray- to brown-weathering; scattered pebbles of jasper; unit shows all gradations between conglomerate and pebbly limestone	12

SECTION 17.—*Section of the Campagrande Formation*

[South side of the eastern part of the Finlay Mountains; traverse 17 shown on pl. 1]

Lower Cretaceous—Cox Sandstone. Lower Cretaceous—Campagrande Formation:	*Thickness (feet)*
8. Limestone, medium light-gray; weathers light olive gray. Upper part contains numerous gastropods (mostly *Nerinea*). Lower 6.7 ft finely oolitic, containing numerous shell fragments. Unit caps cuesta	10
7. Marl, gray, sandy; poorly exposed	29
6. Limestone, light-gray, coarse-textured; scattered pebbles of reddish-brown sandstone as much as an inch across	9

SECTION 17.—*Section of the Campagrande Formation*—Continued

Lower Cretaceous—Campagrande Formation—Continued	*Thickness (feet)*
5. Marl, gray, sandy, interbedded with fine-textured limestone; unit approximately 80 percent marl and 20 percent limestone. Marl units weakly indurated and poorly exposed; contain between 5 and 10 percent fine and very fine quartz sand. Limestone beds between 0.5 and 1.5 ft thick	140
4. Limestone, dark-gray, fine-textured, dolomitic. Lower 5.3 ft contains numerous turritelliform gastropods, coral heads, and horn-shaped rudistids as much as 6 in. long; fossils weather brown and stand in relief on weathered surfaces. Unit nodular toward base	7
3. Unexposed	13
2. Limestone, dark-gray, fine-textured	2.5
1. Limestone, medium-gray, oolitic, grading downward into fine-textured dark-gray limestone. Highly fossiliferous beds near middle of unit contain rudistids and *Porocystis*? Unit in beds 0.5 to 3.5 ft thick; base not exposed	31
Total thickness exposed	242

Beds of limestone from ½ to 3 feet thick occur at intervals throughout the formation, and in places in the lower half they form sequences as much as 24 feet thick. In the upper part of the formation, they alternate with layers of marl.

The limestone is gray on both fresh and weathered surfaces, although a few units are pale olive or brown. Most of the beds consist of fine-textured intergrowths of carbonate minerals and 10 percent or less of clay particles and sand grains; these beds are hard and break conchoidally. Most of the inorganic detrital matter is of sand size or smaller, but pebbly limestones grading into conglomerate occur near the base of the formation. Of six samples chosen as representing the ranges in color and texture in the Finlay Mountains, two contained enough magnesium to be classified as dolomitic or magnesian. (See table 10.)

A bed made of algal pebbles occurs 215 feet above the base of the formation in the reference section. The pebbles are spheroidal, closely packed, and as much as 4 cm across. Viewed in thin section, they seem to be made of cryptocrystalline calcite in filamentous or spongy-textured layers alternating with thinner dense crustiform layers. The spaces between the algal pebbles are filled with mesocrystalline calcite.

Some limestone beds are oolitic, and one bed 24 feet thick lies approximately 135 feet above the algal bed. The rock is laminated and locally crossbedded and has a coarse sandy texture. It is composed predominantly of ooids 0.3 to 0.6 mm in diameter but contains limestone granules scattered throughout and

TABLE 10.—*Analyses of carbonate rocks from the Campagrande Formation*

[Analyst, R. G. Guerrero (1952). See Campagrande Formation sections 1, 3, and 17]

Specimen		Analyses (percent)				Remarks
No.	Classification and locality	Acid insoluble	$CaCO_3$	$MgCO_3$	Nondetermined acid soluble, by difference	
A-112	Limestone, western Finlay Mountains, reference section, unit 16.	3.18	93.04	1.74	2.04	Rock made of algal pebbles, with calcite filling interstices.
A-109	Limestone, western Finlay Mountains, reference section, 20 ft above base of unit 35.	4.83	91.15	2.03	1.99	Rock made mostly of cryptocrystalline calcite; contains doubtful algal filaments.
A-107	Magnesian limestone, western Finlay Mountains, reference section, about 30 ft below top of unit 35.	9.85	82.17	2.49	5.49	Insoluble residue consists largely of quartz silt. Rock contains scattered octahedra of hematite altered from pyrite.
A-103	Limestone, section in eastern Finlay Mountains, unit 8.	2.57	94.93	1.55	.95	A micro-oolite, with ooids and shell fragments set in microcrystalline calcite.
A-110	Dolomitic limestone, section in eastern Finlay Mountains, unit 4.	3.26	89.41	5.33	2.00	A highly fossiliferous rock containing rudistids and gastropods.
A-102	Limestone, eastern Finlay Mountains, unit 1	6.24	90.68	1.28	1.80	Oolitic rock with shell fragments, echinoid spines, and foraminifers.
A-111	Dolomitic limestone, from unit 4 of section at Triple Hill.	.81	85.68	11.15	2.36	Contains numerous small gastropods and shell fragments, many of which are partly replaced by ferruginous material.
A-101	Limestone, from unit 1 of section at Triple Hill	2.69	95.00	1.46	.85	Fine-textured rock with abundant shell fragments, microfossils, and micro-oolites(?).
A-104	Impure calcitic dolomite, about 8 miles east-northeast of Triple Hill.	29.44	39.46	24.55	6.55	Quartz silt makes up approximately half the insoluble residue; remainder is clay. No fossils observed.
A-106	Limestone, about 8 miles east-northeast of Triple Hill.	4.40	92.02	2.20	1.38	About 5 percent of rock consists of shells, which are set in cryptocrystalline matrix of carbonate minerals.

toward the base, many chert pebbles, which locally are concentrated in lenses. Thin sections show quartz grains, foraminiferal tests, echinoid spines and plates, curved spicules, and shell fragments mingled with the oolites (fig. 35). The nuclei of the ooids are quartz grains or bits of limestone, some of which are themselves oolitic. The rock is cemented by calcite in uneven microcrystalline intergrowths. A limestone bed at the top of the formation in the measured section in the eastern part of the Finlay Mountains is very finely oolitic, with ooids only about 0.15 mm in diameter.

Except for a few thin beds in the lower 135 feet of the reference section, all the limestone is fossiliferous or at least contains shell fragments. Some of the beds contain only scattered microfossils (fig. 36), but be-

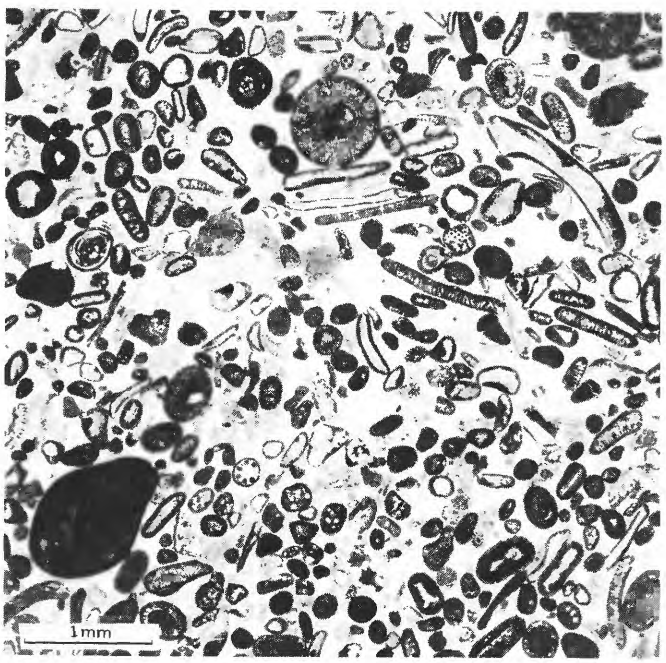

FIGURE 35.—Oolitic limestone from Campagrande Formation (unit 26 of reference section 1 in western part of Finlay Mountains). Rock consists of oolites, quartz grains, rock fragments, microfossils, and fragments of megafossils, all set in microcrystalline calcite. Nuclei of oolites consist variously of sand grains, rock fragments, and bits of shells or spines.

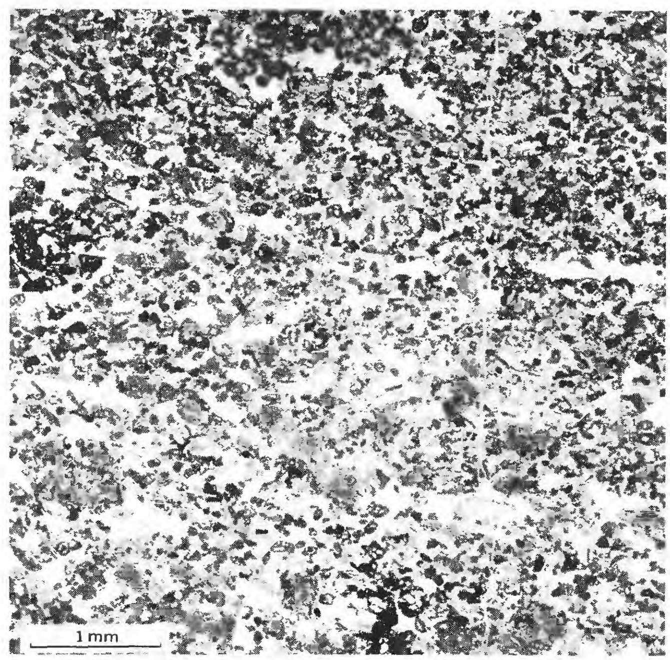

FIGURE 36.—Magnesian limestone from the Campagrande Formation (unit 35 of the reference section 1 in western part of Finlay Mountains). A mixture of quartz silt, formaminiferal tests (mostly miliolids), and ostracodes, all set in mesocrystalline carbonate matrix.

tween 190 and 240 feet below the top of the formation, whole beds are made largely of stony corals, gastropods, and pelecypods. The coral heads are upright, in growth position, and seem to be part of a single widespread biostrome.

Gray marl constitutes roughly 60 percent of the upper 210 feet of the reference section and 80 percent of the equivalent part of the formation in the eastern part of the Finlay Mountains.

The marl is weakly indurated, weathers readily, forms recesses in cliffs, and underlies small valleys between the limestone ledges and ridges, where it is generally concealed by debris. Some of the marl is laminated and fissile, but much of it is massive and occurs in layers of all sizes from a few inches to 30 feet thick.

Four samples chosen at random from different strata lost 56 to 76 percent of their weight in dilute hydrochloric acid. Finely divided carbonate matter is perhaps the largest component of the rock, but calcitic organic material the size of silt and fine sand is also abundant. Such material includes calcite prisms broken from pelecypod shells and fragments of bryozoan colonies, echinoid spines, tests of foraminifers, and ostracodes. Most of the insoluble matter is argillaceous, but three of the four samples examined contain 5 to 10 percent of angular quartz silt and fine sand.

Fine clastic rocks account for about 60 percent of the lower 400 feet of the reference section. About two-thirds of this lower part is silt and sandy shale, and one-third is fine and very fine quartz sand and sandstone. The rocks are buff to yellowish and reddish brown. They are weakly indurated and poorly exposed except in undercut banks along the north side of the main branch of Campo Grande Arroyo east of Wilkie Ranch house, where they display complex scour-and-fill structure and crossbedding (fig. 37). These exposures are within the basal 30 feet of the formation.

Conglomerate units as much as 20 feet thick occur in the lower half of the formation. They are made up principally of well-rounded limestone pebbles and, in the lower parts of some units, cobbles and boulders as much as a foot across. In places, angular chert pebbles form 30 percent of the rock. The matrix is generally a sandy limestone, and some conglomerate grades laterally into pebbly limestone. In some beds the pebbles are so closely packed that they have virtually no matrix except films of calcite cement, and stylolites extend through the pebbles.

Some of the limestone pebbles are fossiliferous and were obviously derived from nearby Permian rocks.

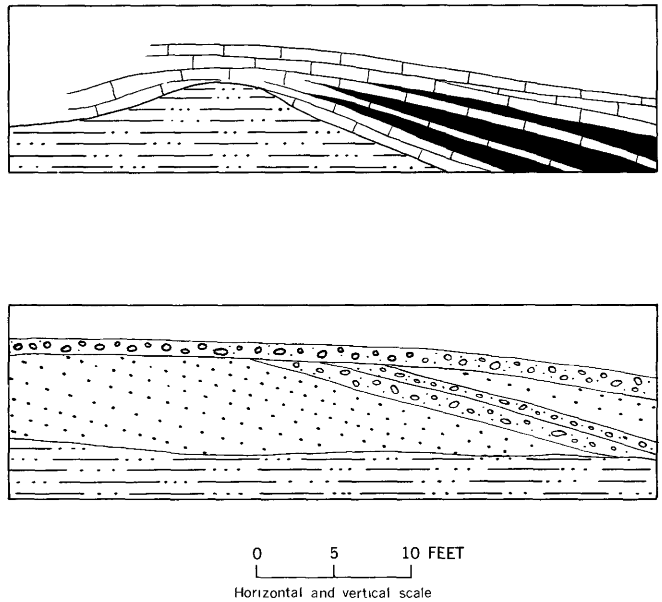

FIGURE 37.—Primary structures in basal part of the Campagrande Formation exposed along headwaters of Campo Grande Arroyo, Finlay Mountains. Top: a buried mound of sandy shale, overlapped by beds of pebbly limestone with partings of black shale (black). Bottom: sandy shale overlain by foreset beds of sandstone and conglomerate, the bed of conglomerate extending across truncated upper edges of the foreset beds.

Much of the conglomerate, however, closely resembles that of the underlying Permian rocks, and in isolated exposures the two are not easily distinguished. Most of the conglomerates of Cretaceous age lack fossils in the matrix and contain many chert pebbles, whereas many of Permian age abound in fusulinids and crinoid stems and contain little chert.

TRIPLE HILL AND AREA TO THE EAST

The Campagrande forms a narrow arcuate outcrop along the west and south borders of the Triple Hill intrusive body. Near the north end of the outcrop, a maximum of approximately 315 feet of the formation is exposed, but to the south the intrusive body cuts out about half of this section. The base of the formation is not exposed.

In this area the formation is mostly fine textured gray limestone, substantially free of sand and other impurities, and evenly bedded in layers 1 to 5 feet thick. At certain levels the rock is sandy and massive, as in uits 4, 6, and 8 of the following section.

SECTION 3.—*Partial section of the Campagrande Formation*

[North end of Triple Hill; traverse 3 shown on pl. 1]

	Thickness (feet)
Lower Cretaceous—Cox Sandstone:	
10. Interbedded sandstone and maroon shale; poorly exposed	21.0

SECTION 3.—*Partial section of the Campagrande Formation*—Con.

Lower Cretaceous—Campagrande Formation:	*Thickness (feet)*
9. Limestone, gray, bedded in units a few inches to a foot thick; arenaceous toward top	28.0
8. Limestone, massive, arenaceous; weathers gray; small gastropods in upper few feet. Unit forms bluff	37.0
7. Limestone, gray; weathers light gray and yellowish brown; 1- to 5-ft beds; locally nodular. Fossiliferous at several horizons	110.0
6. Limestone, massive, arenaceous, containing small gastropods; basal 3 ft locally thin bedded and contains fragments of larger fossils, mostly *Exogyra*?. Unit forms bluff	24.0
5. Limestone, gray, in beds a foot or less thick; largely concealed by rubble	15.0
4. Limestone, gray, containing small gastropods and fragments of shells weathering reddish brown; forms ledge	9.0
3. Limestone composed of (algal?) nodules 1 to 2 in. across	.5
2. Limestone, gray, massive	6.0
1. Limestone, gray, fine-textured; dominantly massive but contains some 1- to 2-ft beds. Basal 2 ft locally silicified along contact with Triple Hill pluton. Base not exposed	87.0
Total exposed thickness, Campagrande Formation	317

Limestone from the lowest unit of the section contains 2.69 percent of insoluble clayey matter, 95 percent calcium carbonate, and 1.46 percent magnesium carbonate and seems to be fairly typical of the Campagrande at Triple Hill. In thin section it appears to be made largely of shell fragments, tests of microfossils, and spherical bodies that are possibly recrystallized oolites. A specimen from unit 4 is dolomitic (specimen A–111, table 10). In thin section it appears to be made largely of shell fragments with scattered whole shells of tiny turreted gastropods. Most of the fragments have been reconstructed as mosaics of carbonate crystals that are coarser than the microcrystalline matrix. The gastropod shells are likewise reconstructed, but their identity is preserved by fillings of mesocrystalline calcite and locally by veinlets of a brown ferruginous material replacing some of the lamellae in the original shell. Bits of iron-impregnated shells weather in relief and give a false impression of high sand content.

About 8 miles east-northeast of Triple Hill, the Campagrande forms ledges and low benches along the base of mesas capped by the Cox Sandstone. The thickness of the formation in this area is not known because the contact with the underlying Permian rocks is concealed and the outcrops are too scattered to establish a reliable sequence of beds. At least the upper few tens of feet consists principally of fine-textured pale yellowish-brown and grayish orange-pink limestone and minor amounts of limestone pebble conglomerate. One specimen collected here is an im-pink limestone and minor amounts of limestone pebble taining about 15 percent angular quartz silt and fine sand in a cryptocrystalline matrix of carbonate and clay minerals. Another (specimen A–106) is a limestone consisting of about 5 percent of turritelliform gastropod shells, shell fragments, ostracodes, and small foraminifers in a cryptocrystalline calcite matrix. A third, identified in the field as a fine-grained sandstone, proved to consist dominantly of miliolid and other foraminiferal tests mixed with carapaces of ostracodes and to contain about 10 percent angular quartz silt and fine sand, all bound together by calcite cement making up about 10 percent of the rock.

UNCONFORMITY AT BASE OF THE CAMPAGRANDE FORMATION

Within the Sierra Blanca area, the base of the Campagrande Formation is exposed only in the western Finlay Mountains, where it rests unconformably on the Leonard Series of Permian age. The hiatus represents all Triassic and Jurassic time and part of the Permian and Cretaceous, yet the angular discordance between beds above and below is only a few degrees in most places and no more than 25° at any place.

The unconformity is best exposed in the headwater reaches of the principal branch of Campo Grande Arroyo, where limestone, conglomerate, and marlstone of the Leonard Series are all cleanly truncated along a remarkably even surface having local relief of a few tens of feet. East of the report area, the unconformity is exposed at many places, especially along the dissected south border of the Diablo Plateau (King and Flawn, 1953, p. 99–100, pl. 2–3). There, the basal Cretaceous deposits rest on rocks older than the Leonard Series—in some places on the Hueco Limestone (Permian, Wolfcamp Series) and in others on the Hazel and Allamoore Formations (Precambrian). Outliers of the Campagrande farther north in the Diablo Plateau lie either on Hueco or Bone Spring (Permian, Wolfcamp or Leonard).

According to P. B. King (1948, p. 140; oral commun., 1948), the surface at the base of the Cretaceous on the Diablo Plateau is very even and was probably leveled mainly by subaerial erosion but partly by marine planation during advance of the Cretaceous seas. East of the report area, along the crest of the Sierra Diablo between Victorio and Apache Canyons, parts of this surface have been stripped of the Cretaceous deposits; they stand at altitudes above 6,000 feet and slant westward beneath buttes and mesas made of the Campagrande Formation.

RELATION TO BLUFF MESA LIMESTONE

The Campagrande Formation is equivalent in part to the Bluff Mesa Limestone, which crops out south of the Devil Ridge thrust. Although the two formations occupy the same stratigraphic position beneath the Cox Sandstone, they differ significantly in lithology. Although they contain many of the same fossils, the Campagrande does not contain the *Orbitolina* or *Exogyra quitmanensis* Cragin characteristic of the Bluff Mesa.

FOSSILS [4] AND AGE

Microfossils are fairly common in limestone and marl throughout the upper 275 feet of the reference section. Thin slices of the oolitic limestone from unit 26 (Campagrande Formation, section 1) show many miliolid and textularid foraminifers, and washed samples of marl from higher in the column contain a variety of arenaceous and calcareous tests.

Some of the foraminifers from the upper 200 feet of the reference section were tentatively identified by M. E. Moss,[5] who reported 30 or more species. The Lituolidae are the most abundant agglutinated forms and include *Haplophragmoides globosus* Lozo, *Ammobaculites subcretaceous* Cushman and Alexander, and *A.* sp. aff. *A. torosus* Loeblich and Tappan. The Miliolidae are represented by several species each of *Quinqueloculina* and *Spiroloculina*. The Polymorphinidae are represented fairly commonly by *Guttulina* sp. aff. *G. symploca* Loeblich and Tappan and *Pseudopolymorphina* aff. *P. plectilis* Loeblich and Tappan. Among the calcareous tests, those belonging to the Rotaliidae are probably the most abundant—*Eponides*, *Discorbis*, and *Patellina* all being well represented. *Globigerina* occurs in most samples but is not abundant in any.

The washed samples of marl from which Moss took her foraminifers also contained fragments of echinoid spines and bits of bryozoan colonies.

Among the megafossils, perhaps the most characteristic is *Porocystis globularis* (Giebel), which occurs throughout the upper 235 feet of the reference section and weathers in great numbers from the limestone of unit 32. This singular fossil—variously placed in such diverse groups as foraminifers, sponges, and plants—is commonly well preserved as spheroidal bodies 1.2 to 3.0 cm in diameter.

Associated with *Porocystis* in the dark limestone of unit 32 are many globular heads of stony corals, some as much as 6 inches across. From our specimens, J. P. Wells identified *Stephanocoenia guadalupae* minor Wells (USGS Mesozoic loc. 23879). The same or a closely similar coral occurs in great numbers near the base of the exposed section in the eastern part of the Finlay Mountains.

Fragments of pelecypod shells may be found in nearly every limestone bed, and whole shells or molds are common throughout the upper 235 feet of the formation. Rudistids are relatively uncommon in the Campagrande but are abundant in unit 32 of the reference section, where the keeled and twisted valves of *Toucasia* are mingled with the spirally curved *Caprina* and cylindrical or conical parts of *Radiolites*. A strongly ribbed *Trigonia*, probably *T. stolleyi* Hill, is associated with the rudistids, together with *Exogyra texana* Roemer and an assortment of shell molds, some of which may be of *Pleuromya* and *Artica*. Molds are even more common in the alternating marl and limestone of unit 35 in the type section and probably represent several genera of pelecypods. The upper 45 feet of this unit contains numerous scallops.

Gastropods are fairly common in the upper 235 feet of the formation. Internal molds referred with question to *Lunatia*, *Tylostoma*, *Nerinea*, and *Nerita* are associated with the rudistids in unit 32. Higher in the section a small *Nerinea* is common, and in the uppermost limestone beds this snail is abundant.

No ammonites were found in the Campagrande Formation, although a careful search was made for them. The stratigraphic position of the Campagrande Formation, its equivalence to the Bluff Mesa Limestone, and its fossil content indicate an Early Cretaceous age for the formation. Like the Bluff Mesa, the Campagrande is probably equivalent to part of the Trinity Group.

CONDITIONS OF DEPOSITION

What appears to be a remnant of fossil soil is exposed along the north bank of Campo Grande Arroyo 2.5 miles east of Wilkie Ranch house (Albritton and Smith, 1950). Here a 3-foot bed of limestone conglomerate forms the base of the Campagrande and lies unconformably on dark limestone and marlstone of the Leonard Series. The upper foot of the limestone and marlstone has a peculiar chalky appearance and consistency; it probably had been weathered and impregnated with calcium carbonate prior to burial. Embedded in the overlying basal conglomerate are scattered subangular pebbles having flattened faces like those found on solution-faceted pebbles (fig. 38). The chalky deposit below the unconformity may thus be part of an ancient caliche bed or lime-enriched subsoil. If so, the climate was dry at sometimes prior

[4] Except as indicated, identification of the fossils was by C. C. Albritton, Jr.

[5] Moss, M. E., 1948, Foraminifera from the Campagrande (Lower Cretaceous) Formation, Finlay Mountains, Tex.: Southern Methodist Univ., Dallas, Tex., unpub. M.S. thesis.

FIGURE 38.—Side views of solution-faceted pebbles. Three in top row were collected from surfaces of pediments bordering the Finlay Mountains. Three in lower row taken from basal conglomerate of Campagrande Formation in Finlay Mountains. Largest pebble in group is 3.5 inches long. (Photographed by Marvin Cullum.)

to deposition of the Campagrande, and solution-faceted pebbles (Bryan, 1929) that formed in limestone gravels (see Bryan and Albritton, 1943) could have been reworked into the basal part of the Campagrande.

The Mesozoic sea continued its northward advance during Campagrande time. Deposition of the equivalent Bluff Mesa and Campagrande Formations marked the first transgression of this sea across the position of the structural boundary between the Sierra Madre Oriental and the Basin and Range provinces. The Campagrande is thicker in the Finlay Mountains than elsewhere in the Diablo Plateau, and deposition presumably began there while bordering areas to the north and east were still undergoing subaerial erosion. Encroachment of the Early Cretaceous seaway over the Diablo Plateau area was probably the result of regional subsidence, but there must have been accelerated downward flexing along the south border. Along this belt, the northward advance of the sea may have been opposed by the building of deltas by streams draining the country to the north. The basal unfossiliferous and varicolored clastic beds in the Campagrande of the Finlay Mountains display cross-bedding and scour-and-fill structures and are more probably fluviatile than marine; they may have been built by streams draining the country to the north. The lowest fossils are in a limestone bed approximately 135 feet above the base of the formation but are fragmental and unidentifiable. The algal limestone 215 feet above the base was clearly subaqueous but contains no certain marine fossils, and the water could have been fresh or brackish. The oldest bed containing fossils that are definitely marine is the oolitic limestone (unit 26, Campagrande Formation section 1), 355 feet above the base, which contains echinoid spines and plates and small foraminifers. By the time of deposition of this oolite, the strand had moved northward past the Finlay Mountains area, and deposition of conglomerate and other coarse clastic material had virtually ceased in these parts. The sea bottom became covered with banks of stony corals and rudistids (unit 32). Thereafter, the accumulation of limy muds was periodically interrupted by influx of clay, resulting in alternating beds of limestone and marl. Sedentary benthonic animals such as corals and rudistids did not flourish on these muddy bottoms, although vagrant clams and gastropods thrived and left abundant remains in the upper 190 feet of the sequence.

By the time the Campagrande sea had spread eastward and northward over the Diablo Platform, the climate of the bordering coastal belt had probably become humid. According to P. B. King (oral commun., 1949), the exhumed surface of unconformity below beds of Cretaceous age in parts of the Diablo Plateau is thinly covered by red and brown residual loamlike material. Pinnacles of the Paleozoic bedrock project upward through the loam in places, and numerous residual nodules of orange-brown chert are scattered over the surface. If this material is fossil soil, its color, content of siliceous materials, and relation to the corroded limestone basement all suggest weathering under conditions more humid than those responsible for the caliche and the solution-faceted pebbles at the base of the Campagrande in the Finlay Mountains.

Along the south border and outlying foothills of the Diablo Plateau, the Campagrande is heterogeneous in the extreme. The basal beds apparently represent a reworked assortment of whatever residual mantle and alluvial deposits lay in the path of the invading sea. Most of these deposits are conglomerates of limestone and chert pebbles and cobbles. In most places the basal conglomerate is unfossiliferous, but Richardson (1914) found fragments of *Exogyra* in the sandy matrix of basal conglomerate at Three-Mile Ridge about 18 miles east of the report area and north of the Texas and Pacific Railway. This fact suggests that at least some of the conglomerate is a marine deposit, perhaps a beach shingle reworked from fluviatile gravels. The limestone and marl above the conglomerates contain foraminifers, algal pebbles, echinoids, oysters, and gastropods and thus are largely marine.

COX SANDSTONE

DEFINITION

The Cox Sandstone was named by Richardson (1904, p. 47) for a butte 15 miles northeast of the town of Sierra Blanca and east of the report area; this butte was known as Cox Mountain but now is designated on most maps as Tabernacle Mountain or Sneed Mountain. Although named for Cox Mountain, the formation was defined on the basis of exposures in the Finlay Mountains, where stratigraphic relations are somewhat different from those on Cox Mountain. Subsequently, the name was extended by Baker (1927, p. 18-20) and was applied to the sandstones in the disturbed area to the south, where stratigraphic relations are still different.

The name Cox is used for a heterogeneous body of sandstone and associated clastic rocks which is varied in detail and not entirely of the same age from place to place. The Cox is conformable on the underlying Campagrande Formation (or the equivalent Bluff Mesa Limestone) and is conformable beneath the Finlay Limestone.

The Cox Sandstone is exposed around the edges of the two domical uplifts in the Finlay Mountains, where its position in the sequence between the Campagrande and Finlay is well displayed. Farther eastward and northward, it is largely hidden beneath the Finlay Limestone and younger rocks for several miles, but it emerges in the structural uplifts of Granite Mountain, Gunsight Hills, and Triple Hill. The Cox is at the surface in the northeastern part of the report area, as at Round Mountain, and from there extends eastward with interruptions to the type locality on Sneed (Cox or Tabernacle) Mountain (fig. 1). In the disturbed belt in the southeastern part of the report area, the Cox forms long prominent belts of outcrop on Devil Ridge and in the Quitman Mountains, where it lies between the Bluff Mesa and Finlay Limestones.

Two sections in the western and eastern parts of the Finlay Mountains indicate the character and relations of the Cox Sandstone there.

SECTION 1.—*Section of the Cox Sandstone*

[Western part of Finlay Mountains; traverse 1 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

	Thickness (feet)
Lower Cretaceous—Finlay Limestone:	
48. Marl, sandy; poorly exposed	9.0
Lower Cretaceous—Cox Sandstone:	
47. Sandstone, yellowish-gray, quartzitic, very fine-grained, cross-laminated	1.0
46. Sandstone, friable, ferruginous, fine- to medium-grained	3.5
45. Sandstone, brown, ferruginous, cross-laminated; caps minor cuesta	5.0
44. Unexposed. Slope covered with fragments of light-brown sandstone and gray limestone. Limestone contains fragments of *Exogyra* and *Gryphaea*	13.0
43. Sandstone, fine- to coarse-grained, in alternating hard quartzitic and weakly consolidated beds; color variable, but mostly near reddish orange; most layers cross-laminated, containing scattered chert pebbles; joint blocks having hard rinds of brownish-gray desert varnish	98
42. Sandstone, friable, interbedded with dark limestone near base; poorly exposed; slope littered with black shells of *Exogyra texana* Roemer, *Protocardia cf. P. texana* Conrad, *P. aff. P. multistriata* Shumard, and *Trigonia crenulata* Roemer (not Lamarck)	22.0
41. Limestone, medium-gray, clastic, consisting mostly of shell fragments cemented with calcite; accessory granules and pebbles of chert; contains *Actaeonella dolium* Roemer, *Exogyra texana* Roemer, and *Protocardia* spp	3.5

SECTION 1.—*Section of the Cox Sandstone*—Continued

Lower Cretaceous—Cox Sandstone—Continued	Thickness (feet)
40. Limestone, flaggy, arenaceous; shell fragments abundant, forming coquina lentils toward base	5.0
39. Limestone, thinly bedded, gray, containing *Actaeonella dolium* Roemer; poorly exposed	3.0
38. Sandstone, medium-gray, calcareous; weathers pale yellowish brown; forms ledge; contains abundant turritelliform gastropods and scattered fragments of *Exogyra* sp	1.5
37. Limestone, flaggy, gray, arenaceous, containing partings of sandy shale; grades downward into nodular gray and brown limestone crowded with *Actaeonella dolium* Roemer	11.0
36. Limestone and shale, interbedded; partings of shale crowded with *Actaeonella dolium* Roemer	3.0
35. Quartzite, laminated, green	3.0
(Sill of hornblende porphyry 12 ft thick.)	
34. Limestone, gray, nodular, interbedded with gray calcareous shale; locally crossed by dikes following minor faults; thickness approximate	45.0
33. Sandstone, calcareous, gray; contains abundant *Exogyra texana* Roemer and *Serpula* sp	3.0
32. Shale, gray, sandy	6.0
31. Sandstone, weakly indurated, brown, cross-laminated	3.5
30. Unexposed	12.0
29. Limestone, dark-gray, mottled brownish on weathered surfaces. Contains *Exogyra texana* Roemer and *Actaeonella dolium* Roemer	1.5
28. Shale, gray, calcareous; contains limestone nodules	9.5
27. Siltstone, yellowish-gray, calcareous, finely laminated; contains *Globigerina* aff. *planispira* Tappan, *Anomalina* sp., *Bythocypris rotundus* Vanderpool, and *Paracypris weatherfordensis* Vanderpool	2.5
26. Unexposed	8.0
25. Limestone, dark-gray, fine-textured, containing *Exogyra* sp., *Trigonia* sp., and *Protocardia* sp	13.0
24. Quartzite, grayish-green, fine-grained, laminated	2.5
23. Shale, silty, dominantly gray; yellowish brown toward base; contains thin beds of nodular limestone and calcareous sandstone	53.0
22. Sandstone, fine-grained, gray, calcareous	2.0
21. Shale, brown, sandy, containing partings of impure limestone	15.0
20. Sandstone, light-brown, quartzitic	.5
19. Shale, sandy	1.0
18. Sandstone, hard, brown, cross-laminated	6.0
17. Unexposed	11.0
16. Limestone, gray, sandy, nodular	2.0
15. Shale, brown, sandy, poorly exposed	27.0
14. Sandstone, fine-grained, gray, having brown coating of desert varnish; contains scattered polished siliceous pebbles (gastroliths?)	2.5
13. Silt, gray and brown, interbedded with sandy shale	14.0
12. Sandstone, brown, quartzitic	3.0
11. Silt, gray	23.0
10. Limestone, dark-gray, sandy	.5

SECTION 1.—*Section of the Cox Sandstone*—Continued

Lower Cretaceous—Cox Sandstone—Continued	Thickness (feet)
9. Siltstone, yellowish-gray, calcareous, grading downward into laminated pale reddish-brown calcareous and ferruginous siltstone and very fine sandstone. Contains ostracodes and charophytes: *Bythocypris rotundus* Vanderpool; *Chara* spp., and *Aclistochara cylindrica* Peck	42.0
8. Sandstone, brown, having dark-brown coating of desert varnish	15.0
7. Silt and fine sand, interbedded, light-brown	11.0
6. Sandstone, brown, cross-laminated	15.0
5. Silt and fine sand, interbedded, brown, poorly exposed	18.0
4. Sandstone, brown, quartzitic, containing numerous polished pebbles	1.5
3. Silt and fine sand, reddish-brown, interbedded with grayish-red quartzitic sandstone	22.0
2. Sandstone, gray, weathering brown, cross-laminated, laminae cut by linear borings as much as 1 cm in diameter	2.5
1. Siltstone, pale-brown and pale yellowish-brown, calcareous, fissile; thin partings of impure limestone; contains abundant charophytes: *Chara* aff. *verticellata* Peck and *Clavator* cf. *harrisi* Peck. Poorly exposed, thickness approximate	104.0
Total thickness	670.0

Lower Cretaceous—Campagrande Formation:
Limestone, gray.

SECTION 2.—*Section of the Cox Sandstone*

[Eastern part of the Finlay Mountains; traverse 2 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

Lower Cretaceous—Finlay Limestone.

Lower Cretaceous—Cox Sandstone:	Thickness (feet)
57. Sandstone, brown, cross-laminated, quartzitic toward base	3.0
56. Marl, gray	19.0
55. Limestone, gray, fine-textured	.1
54. Unexposed	17.0
53. Sandstone, medium-grained, grayish-orange (beneath brown rind of desert varnish), cross-laminated; contains rounded pebbles of milky quartz in lentils or as scattered individuals	3.5
52. Unexposed	6.5
51. Sandstone, thinly bedded, ferruginous	5
50. Unexposed, except for scattered sandstone outcrops near base	17.0
49. Limestone, fragmental, gray, consisting largely of shell fragments; contains *Actaeonella dolium* Roemer and *Exogyra texana* Roemer	4.0
48. Unexposed	19.0
47. Sandstone, brown, quartzitic	1.5
46. Limestone, yellowish-gray, marly, interbedded with nodular limestone	16.0
45. Limestone, gray, nodular, containing *Exogyra texana* Roemer	20.0
44. Sandstone, brown, cross-laminated; caps minor cuesta	8.5

SECTION 2.—*Section of the Cox Sandstone*—Continued

Lower Cretaceous—Cox Sandstone—Continued	Thickness (feet)
43. Unexposed. Blocks of limestone crowded with *Actaeonella dolium* Roemer weather from near top of unit	11
42. Limestone, gray, arenaceous; numerous shell fragments	.3
41. Unexposed	.5
40. Sandstone, gray, calcareous; weathers brown	.3
39. Mostly unexposed. Scattered outcrops of fine-textured medium-gray nodular limestone containing turretelliform gastropods and shell fragments	18.0
38. Quartzite, fine-grained, reddish-brown, pebbly	1.0
37. Sandstone, brown, cross-laminated, having thin layer of pebble conglomerate locally at base	9.0
36. Shale, gray, sandy, containing nodules of medium dark-gray limestone	21.0
35. Sandstone, quartzitic, fine-grained, dark-gray	.6
34. Unexposed	2.0
33. Sandstone, brownish, in units between a fraction of an inch and 2 ft thick; thicker beds are cross-laminated, foreset laminae dipping toward west and southwest; caps minor cuesta	22.0
32. Unexposed	46.0
31. Quartzite, fine-grained, gray	1.5
30. Shale, reddish-brown, sandy, poorly exposed	18.0
29. Sandstone, coarse-grained, brown, cross-laminated; foreset beds inclined toward west and southwest; caps cuesta	16.0
28. Unexposed	18.0
27. Sandstone, gray, calcareous, grading upward into nodular arenaceous limestone	8.0
26. Sandstone, medium-grained, gray, brown-weathering, containing scattered pebbles of limestone	5.5
25. Unexposed; probably sandy shale	40.0
24. Sandstone, light-gray, fine-grained cross-laminated; weathers dark yellowish brown; foreset beds dip toward the west	1.5
23. Shale, yellowish-brown, sandy, poorly exposed	10.0
22. Sandstone, fine-grained, quartzitic, brown (beneath dark-brown rind of desert varnish); caps cuesta	2.5
21. Shale, reddish-brown, sandy, poorly exposed	30.0
20. Sandstone, quartzitic, reddish-brown, fine-grained	2.5
19. Shale, gray and brown, poorly exposed	22.0
18. Sandstone, fine-grained, brown	2.5
17. Shale, yellowish-brown, sandy	4.0
16. Sandstone, fine-grained, gray; weathers light brown	1.5
15. Shale, yellowish-brown, sandy, containing abundant nodules of white and pink gypsum several inches across	17.0
14. Limestone, fine-textured, gray; weathers brown	1.5
13. Shale, light-brown	1.5
12. Limestone, fine-textured, gray; weathers brown	1.0
11. Shale, light-brown	1.5
10. Limestone, gray, argillaceous	1.0
9. Marlstone, pale yellowish-brown, silty, gypsiferous	8.5

SECTION 2.—*Section of the Cox Sandstone*—Continued

Lower Cretaceous—Cox Sandstone—Continued	Thickness (feet)
8. Siltstone, light olive-gray, calcareous; encloses nodules of milky gypsum as much as half an inch in diameter	4.0
7. Gypsum, white, silty	2.5
6. Siltstone, gray, calcareous	6.0
5. Siltstone, yellowish-gray, calcareous; contains *Praechara voluta* Peck and *Cypridea* aff. *C. wyomingensis* Jones	2.5
4. Sandstone, fine-grained, light-gray; weathers brown; contains pebbles of sandy limestone	2.0
3. Siltstone, pale yellowish-brown, calcareous, containing abundant crystals of selenite and rosettes of salmon-colored gypsum; also contains poorly preserved charophytes, foraminifers, and ostracodes (*Perimneste*? sp., *Conorbina*? sp. and *Cypridea* sp.)	30.0
2. Limestone, gray, arenaceous	1.5
1. Silt, brown, gypsiferous	12.5
Total thickness	549

Lower Cretaceous—Campagrande Formation:
Limestone, gray.

SEDIMENTARY FACIES

The Cox Sandstone is lithologically heterogeneous, consisting of three sedimentary facies that interfinger in a complex manner (fig. 39).

Siltstone-shale facies

West of a line through Yucca Mesa and Triple Hill and north of a line connecting Yucca Mesa with Campo Grande Mountain, shale and siltstone are dominant. They are concentrated in the lower half of the formation and are interbedded with sandstone and limestone in the upper half (pl. 6). In the Finlay Mountains the lower part of the formation contains scattered crystals and nodules of selenite and at least one lentil of rock gypsum. Wells drilled at the Gunsight Hills and to the west also penetrated gypsiferous shale toward the base of the formation.

Sandstone-quartzite facies

East of the area of siltstone and shale and north of the Red Hills thrust, sandstone and quartzite are dominant. The exposures at Triple Hill are transitional between the sandy and the shaly facies. Here the rock is dominantly sandstone, but about a fourth of it consists of shale and siltstone. As in the area to the west, the finer clastic rocks are concentrated in the lower half of the formation.

At Round Mountain, Yucca Mesa, and Devil Ridge, sandstone forms 93 percent or more of the Cox, and limestone and shale, the remainder. The sandstone becomes perceptibly coarser, more persistently crossbedded, and more pebbly toward the east, in expo-

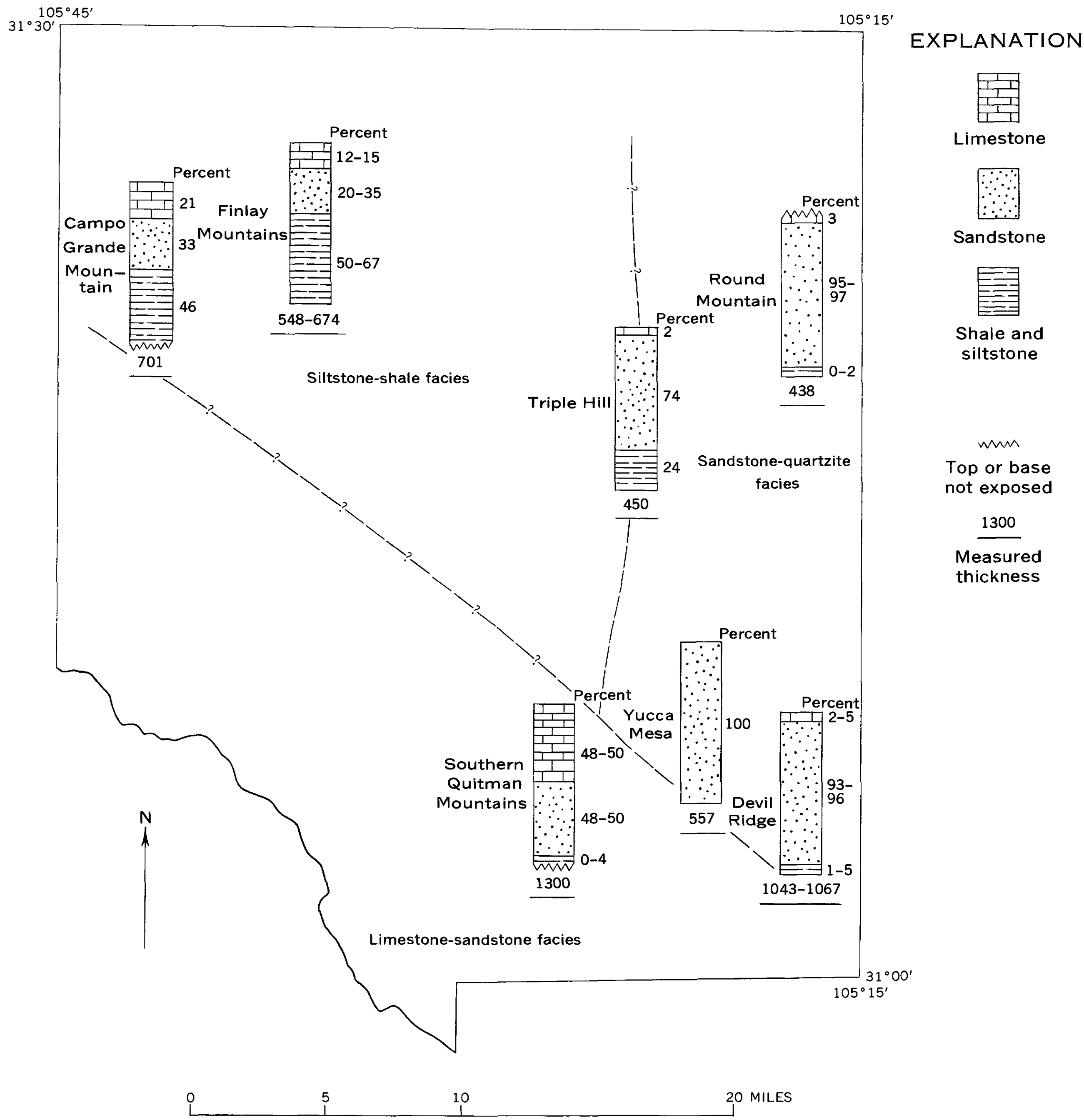

FIGURE 39.—Areas of different facies and percentages of limestone, sandstone and quartzite, and shale and siltstone in measured sections of the Cox Sandstone in the Sierra Blanca area.

sures along the southern part of the Diablo Plateau. It is better indurated and more quartzitic in Devil Ridge than to the north.

Limestone-sandstone facies

In the southern part of the Quitman Mountains, the formation is about half limestone and half sandstone; shale and siltstone make up no more than 4 percent. In general, the lower fourth is dominantly quartzitic sandstone; the middle half is limestone; and the upper fourth is interbedded sandstone and quartzite.

THICKNESS

The Cox Sandstone is notably uneven in thickness, ranging from 450 feet at Triple Hill to about 1,300 feet in the Eagle Mountains east of the map area (Smith, 1941, p. 72; Gillerman, 1953, p. 21). It has a general pattern of northward thinning and also thins along an axis extending northward from Yucca Mesa through Triple Hill. Thickness changes in relation to this axis may be observed along the strike of the beds in the upper plate of the Devil Ridge thrust. Continuation of the axis of thin sandstone to the north of Triple Hill is uncertain because of lack of exposures and drill data. Available well data indicate that the Cox is about 560 feet thick at the Gunsight Hills and about 500 feet on the plateau between Granite Mountain and the Finlay Mountains. (See interpretive logs.)

On the south side of Yucca Mesa, the Cox is 557 feet thick, but it increases to 1,043 feet about 2 miles to the southeast in Devil Ridge (pl. 4) and remains between 1,000 and 1,300 feet farther to the east. At Campo Grande Mountain it is 700 to 740 feet thick, and in the Finlay Mountains, 540 to 675 feet thick.

LITHOLOGY

The sandstone and quartzite of the Cox consist principally of angular to subrounded quartz grains but contain 2 to 5 percent of detrital chert. Some thin layers contain many shell fragments, and many beds of fine-grained quartzite contain minute grains of a birefringent and weakly pleochroic mineral, probably glauconite, which imparts a greenish cast to the rock. The sand grains are very fine to coarse, the fine and medium grades predominating, and are well sorted in most beds. In most of the rocks, the grains have secondary overgrowths of quartz; where these are strongly developed, the rock is quartzitic; elsewhere it is friable and in part cemented by calcite. Limonitic films, possibly derived by oxidation of authigenic pyrite, cover many of the quartz grains and give the sandstone a mottled to uniformly brown color. Commonly, this rusty material is secondarily concentrated on weathered surfaces as hard rinds several inches thick.

Much of the sandstone is cross-laminated. Sets of laminae a few inches to several feet thick lie between more gently dipping plane surfaces of erosional origin. Some of the erosional surfaces are irregular, and sections of shallow channels several feet across are preserved beneath them. The thinner layers of sandstone and quartzite ordinarily show minute cross-laminations like those of rippled sediments, and their bedding surfaces are marked by both oscillation and current ripples. The sandstone beds are mostly 1 to 3 feet thick, but some are as much as 20 feet. Individual beds ordinarily cannot be traced for distances of more than a few hundred yards, although groups of lenticular sandy beds may persist for several miles at about the same stratigraphic level.

Pebbles of limestone, milky quartz, and gray chert an inch or two across are scattered through many of the beds and locally form lentils of conglomerate. In general, this coarse material is more abundant in the west than in the east. Beds of conglomerate as much as a foot thick are fairly common at Devil Ridge and along the edge of the plateau farther north.

Both biogenic and clastic limestones occur in the Cox. Accumulations of large benthonic shells locally form lentils or whole beds. The clastic limestone consists of such shells and their fragments, mixed with sand and finer detritus. The two types intergrade, but the clastic varieties are more common.

The clastic limestone is gray, fine textured, and unevenly bedded in layers a fraction of an inch to several feet thick. In some places it forms partings in the thicker argillaceous and sandy sequences; elsewhere, it forms units 75 to 100 feet thick. Much of the finer textured material is lumpy or nodular. Grains of quartz commonly stand in relief on weathered surfaces, and in some outcrops they outline a cross-lamination. Some of the limestones are not megascopically clastic, but microscopically they consist of fossil fragments and fine-grained quartz sand in a matrix of microcrystalline calcite.

The biogenic limestones are formed largely of pelecypods and gastropods. In the Finlay Mountains, large exogyrate oysters and globular snails form lenses several inches thick at various horizons near the top of the formation. At Campo Grande Mountain and in the southern Quitman Mountains, some beds several feet thick consist largely of rudistids.

Fine-textured rocks made up dominantly of angular quartz silt are most common in the lower half of the formation in the Finlay Mountains. They form units a few feet to more than 100 feet thick, the thicker ones generally containing partings of limestone, sandstone, and quartzite. Many of the siltstone beds are laminated.

Component quartz grains in most places are coated with an iron oxide that imparts pale-yellowish or reddish-brown tints to the aggregate and makes the rock friable. Some of the siltstone has a calcite cement, which holds the grains together more firmly. Total carbonate content of the calcareous siltstone in our specimens ranges from 12 to 37 percent.

The shale is laminated and fissile, consists dominantly of clay containing 5 to 25 percent of admixed quartz silt and sand, and weathers reddish brown or yellowish brown. The shale forms filmy partings between limestone or sandstone beds and also forms units as much as 50 feet thick, the thickest occurring at Campo Grande Mountain, where shale makes up most of the lower half of the formation. The shale generally contains a little calcium carbonate and, where interbedded with limestone, scattered calcareous nodules several inches across.

Marl is a scarce rock type in the Cox. Two units (9 and 56) in stratigraphic section 2 in the eastern part of the Finlay Mountains are gray to pale yellowish brown, break with an earthy fracture, and consist of clay and accessory fine silt bound together with calcium carbonate. Analyses indicate that carbonate minerals make up about half of both of these units. No megafossils or microfossils were seen.

RELATION TO BLUFF MESA LIMESTONE AND CAMPAGRANDE FORMATION

The contact between the Cox Sandstone and the underlying Bluff Mesa Limestone or Campagrande Formation is a sharply defined and conformable surface separating limestone below from sandstone and quartzite above. Even in the southern Quitman Mountains, where the Cox contains much limestone, the basal beds are largely of sandstone and quartzite, and the contact with the Bluff Mesa is reasonably sharp. This sharp contact, however, cannot be at the same horizon everywhere. Detailed sections measured along Devil Ridge show that the two formations interfinger and are partly equivalent (section 7, pl. 4). In the lower part, the Cox Sandstone contains much calcareous sandstone that probably grades laterally into the upper part of the Bluff Mesa Limestone on Yucca Mesa, as shown in section 6, pl. 4. Farther southeast, the thickness remains constant (pl. 4), but the lower part of the Cox is not as calcareous. In the two formations together, limestone decreases and sandstone increases southeastward.

FOSSILS

Although the Cox is on the whole less fossiliferous than the formations above or below, its fossils are ecologically more diverse, including remains of terrestrial and aquatic plants as well as assemblages of marine invertebrate animals. In the southern part of the Quitman Mountains, where the formation is thickest and most calcareous, marine gastropods and pelecypods occur throughout the sequence, and only marine fossils have been found. Farther north, this marine fauna is restricted to the upper part of the formation, and the lower part contains little except charophytes, ostracodes, and silicified wood.

Fossils are most abundant and best preserved in the western part of the Finlay Mountains, from which most of our collections were made. Identifications were made by Albritton.

Charophytes

In the western part of the Finlay Mountains, the basal 104 feet of the Cox contains abundant charophytes. Most of the oogonia are not enveloped in utricles, and most have the closed summits characteristic of the genus *Chara*. Specimens average about 0.37 mm long and 0.34 mm in diameter. Except for their smaller size and slightly more globular form, they are like *Chara verticillata* Peck from the Morrison Formation of Late Jurassic age of Wyoming (Peck, 1937, p. 84–85). A few specimens, completely enveloped in utricles, show the bilateral symmetry and the pattern of ridges and furrows that identify them as *Clavator*. These specimens measure about 0.48 mm long and 0.35 mm thick. Except for their smaller size, they are like C. *harrisi* Peck, a species in the Glen Rose Limestone of Early Cretaceous age of Texas (Peck, 1941, p. 292–294).

At least three species are present in unit 9 of Cox Sandstone section 1 measured in the western part of the Finlay Mountains. One is *Aclistochara cylindrica* Peck, previously reported from Idaho and Wyoming in the Bear River Formation and Draney Limestone of Early Cretaceous age (Peck, 1941, p. 292–294; 1957, p. 38). Two are species of *Praechara*: one may be *P. voluta* Peck, which occurs in the Upper Jurassic Morrison Formation and Lower Cretaceous Aptian formations and Bear River (Albian) Formation in the Rocky Mountain region (Peck 1957, p. 39); the other resembles an unnamed species described by Peck (1937, p. 85–86; 1941, p. 289) from the Kootenai Formation of Early Cretaceous age in Montana.

Tiny oogonia of *Praechara voluta* Peck occur in the eastern part of the Finlay Mountains in unit 5 of stratigraphic section 2 about 50 feet above the base of the Cox, and a single specimen of *Perimneste*? sp. was found in unit 3.

Petrified wood

Silicified logs and branches as much as several feet long and 10 inches across are common in sandstone beds in the north half of the Sierra Blanca area. In the Finlay Mountains the wood is principally in the lower half of the formation and in the upper 110 feet. At Campo Grande Mountain it is confined to the upper 85 feet of the formation. The logs lie about parallel with the bedding, and none occur in position of growth.

Foraminifers

The only foraminifer found in the lower half of the formation came from the western part of the Finlay Mountains. It is a trochoid test that is not well enough preserved to permit positive assignment to genus but has the general shape of *Conorbina*. Samples from 415 feet above the base in the upper half of the formation contain scattered tests of fragmental *Anomalina* and *Globigerina.* The latter resemble *Globigerina almadenensis* Cushman and Todd from the Franciscan Formation of Jurassic and Cretaceous age of California and *G. planispira* Tappan from the Washita Group of Texas—they have the roughened surface of the California species and the smaller dimensions of the Texan species.

Gastropods

Actaeonella dolium Roemer is one of the most abundant gastropods and certainly the largest species. Specimens range in height from 50 to 120 mm and are of ovate type; those from the Sierra Blanca area differ somewhat from the typical form (Stanton, 1947, p. 110). The species occurs from about 430 to 535 feet above the base of the formation in the western part of the Finlay Mountains and from 405 to 475 feet above the base in the eastern part. The species is common on Campo Grande Mountain between 50 and 345 feet below the top of the formation but is missing from the upper 190 feet farther north around Thaxton Spring (pl. 6). At Devil Ridge the species is common 350 feet below the top of the formation, and in the southern part of the Quitman Mountains it ranges from near the bottom to near the top. Despite its erratic distribution, the species is at present the best index fossil for the Cox Sandstone.

Large gastropods associated with *Actaeonella* are mostly internal molds for which even generic assignments are doubtful. They include *Lunatia? praegrandis* (Roemer) and *L.? pedernalis* (Roemer), both of which are common in the Glen Rose Limestone of central Texas. *Tylostoma* probably is represented by several indeterminate species. Rarely, also, there is an *Amauropsis* that closely resembles *A. pecosensis* Adkins but is smaller.

Sections of *Turritella* show on weathered limestone surfaces, and short segments of a large *Nerinea* (cf. *N. aquilina* Stanton) weather from some of the limestone beds.

Pelecypods

Among the pelecypods, *Exogyra texana* Roemer is the most common; it is generally associated with the *Actaeonella* but has a greater range, as it extends through the upper part of the Cox and into the Finlay Limestone. Individual shells are 50 to 80 mm long and 40 to 60 mm wide. Suites of specimens show all the variations in shape and sculpture for which this species is well known. *E. texana* var. *weatherfordensis* Cragin may also be present; however, even the smallest shells found are considerably larger than the types of this variety, and they lack the large attachment scars and relatively smooth surfaces supposed to be characteristic of the variety.

The beds that contain *Exogyra* also contain some other pelecypods. These include numerous well-preserved *Trigonia crenulata* Roemer (not Lamarck) in the Finlay Mountains and large *Caprina* sp. in the southern Quitman Mountains. *Ostrea* aff. *franklini* Coquand, *O.* cf *riograndensis* Stanton, *Gryphaea?* sp., and *Pecten* spp. are known only from scattered fragments. *Protocardia* cf. *texana* Conrad and *P.* aff. *multistriata* Shumard are represented by a few whole shells and many molds. A variety of molds probably includes *Cyprimeria*, *Unicardium*, *Cardium*, *Homomya*, and *Gervillia.*

Cephalopods

Although a careful search for ammonites was made in the more fossiliferous parts of the formation, none were found in place. A few fragments of *Engonoceras* sp. were found in loose limestone that apparently came from the upper part of the Cox.

Worms

Wherever pelecypods are abundant, the calcareous tubelets of *Serpula* are also likely to be found. Individual tubes are sinuous and are 1.5 to 4 mm in diameter. Some encrust clam shells; others are interwoven to form pebble-sized masses embedded in limestone.

Ostracodes

The calcareous siltstones of the Finlay Mountains commonly contain numerous ostracodes. A species of *Cypridea*, closely allied to and possibly identical with *C. wyomingensis* Jones, occurs in the lower 50 feet of the section in the eastern Finlay Mountains. This species is widely distributed throughout the nonmarine deposits of Early Cretaceous age in the Rocky Mountains (Peck, 1941). *Bythocypris rotundus* Vanderpool ranges through roughly the middle third of the Cox Sandstone in the western part of the Finlay Mountains. It is abundant at an horizon about 190 feet above the base of the Cox, where it is associated with charophytes. Some 230 feet higher in the section, the same species is found in association with foraminifers and also with the ostracode, *Paracypris weatherfordensis* Vanderpool. Both of these ostracodes are abundant in the Glen Rose Limestone of northern Texas (Vanderpool, 1928, p. 102, 106).

Possible gastroliths

Rounded quartz pebbles with exceptionally smooth and polished surfaces are common in the Cox Sandstone of the Finlay Mountains, especially in the lower 275 feet. Possibly these pebbles are gastroliths of aquatic terrestrial reptiles, but no bones or tracks of vertebrate animals were found.

AGE AND CORRELATION

Of all the units in the Sierra Blanca area, the Cox Sandstone seems to transgress time boundaries most markedly, extending from probable Trinity age in the south to late Fredericksburg age at Sierra Prieta north of the report area (Adkins, 1932, p. 354).

At the south end of the Quitman Mountains, about 15 miles south of the report area, Scott (1939, p. 978) tentatively correlated a unit he called Glen Rose with the upper part of the Glen Rose and Paluxy Formation of Louisiana. A rapid reconnaissance and study of aerial photographs suggest that Scott's Glen Rose of the Quitman Mountains is equivalent in part at least to the Cox Sandstone of the Sierra Blanca area; thus, part of the Cox in the southern part of the report area is probably of Trinity age.

In the northeastern part of the area, the contact between the Cox and the overlying Finlay Limestone is gradational, and sandstone in the Finlay is like that in the Cox and becomes more abundant farther northeastward. Limestone of the Finlay is missing still farther northeastward at Sierra Prieta (Adkins, 1932, p. 354) where post-Finlay units rest on the Cox; here the Cox evidently is the lateral and time equivalent of the Finlay of Fredericksburg age.

Actaeonella dolium Roemer, a common fossil in the Cox, is reported only from Fredericksburg strata (Stanton, 1947, p. 110). As it occurs within about 100 feet of the base of the formation in the southern part of the area, it may have a longer range than has been recognized. As mentioned previously, Stanton (1947, p. 110) reported that specimens from this area differ somewhat from the typical form. If this fossil is restricted to Fredericksburg rocks, only the lower 100 feet of the southern outcrops of Cox can be of Trinity age.

CONDITIONS OF DEPOSITION

The Cox Sandstone comprises marine, littoral, and related nonmarine sediments deposited during parts of Trinity and Fredericksburg time by the northward spreading sea whose history we have been following. The northward advance of this sea was not simple but was interrupted many times, as shown by the alternate transgressive and regressive shallow water deposits and even nonmarine deposits of the Cox. In general, however, the littoral or nonmarine sand facies becomes younger northward, and the more purely marine deposits of the upper part of the Cox and the overlying Finlay Limestone followed in succession.

The change from marine to littoral and continental deposits is reflected broadly in the change from a thicker limestone-sandstone facies in the south to a thinner sandstone and siltstone facies in the north and in the general coarsening of the sandstone from Devil Ridge northward. The fossils indicate that whereas all or nearly all the section in the southern part of the Quitman Mountains is marine, in the north only the upper part is marine. The contrast between marine and nonmarine assemblages of fossils is particularly striking in the Finlay Mountains, where fresh-water ostracodes and fresh- or brackish-water charophytes in the lower half of the formation are succeeded by marine pelecypods and gastropods in the upper half. Gypsiferous red beds in the lower 90 feet suggest deposition in strongly saline lagoons bordering the shore.

Persistence of marine fossils in the upper part of the formation indicates that the Mexican sea covered most or all the area by the end of Cox time. *Actaeonella* has been found at Granite Mountain, in the northernmost exposures of the Cox Sandstone in the Sierra Blanca area.

The abundant trunks and branches of trees in the northern deposits of sandstone represent driftwood transported by currents along nearby shores or brought to the sea by rivers. Although we made no statistical analysis of cross-lamination in the sandstone, observations of many foreset beds and current ripples along the Diablo Plateau and the Finlay Mountains indicate that the prevailing currents moved toward the west.

FINLAY LIMESTONE

DEFINITION AND GENERAL FEATURES

The Finlay Limestone was named by Richardson (1904, p. 48) for exposures "in the outer rim of the Finlay Mountains," without indicating a specific type locality. He described it in most general terms and noted that it consists almost entirely of massive gray nonmagnesian limestone with local partings of brown sandstone. He did not observe the top of the formation in the Finlay Mountains area but estimated the minimum thickness as 300 feet. The Finlay has a conformable and gradational contact with the underlying Cox Sandstone and a conformable contact with the overlying Kiamichi Formation.

The Finlay Limestone is the most extensively exposed formation in the Sierra Blanca area. It caps nearly all the Diablo Plateau, forms an outer ring of cuestas and buttes around the Finlay Mountains, and crops out on Triple Hill, Flat Mesa, Texan Mountain, Devil Ridge, and in the southern part of the Quitman Mountains.

The Finlay also is the most uniform of the Mesozoic formations in the area. South of the Diablo Plateau, it consists almost entirely of hard gray limestone, but on the plateau the limestone is interbedded with marl. The hard limestone layers generally weather in relief above the marl and nodular limestone, and the flat-lying strata of the plateau thereby form series of steps on the sides of the mesas. The formation contains a little sandstone, which increases in quantity northeastward and forms thin layers and lenses on the plateau. The large foraminifer, *Dictyoconus walnutensis* (Carsey), occurs in the limestones over the entire area, and rudistids are abundant, especially on the Diablo Plateau.

Like all the older Cretaceous formations, the Finlay thins northward, from about 510 feet in the southern Quitman Mountains to about 130 feet at the northeast edge of the Sierra Blanca area. The Finlay is absent at Sierra Prieta, about 6 miles northeast of the report area (Adkins, 1932, p. 345), and must wedge out a little southwest of Sierra Prieta.

LITHOLOGY

Finlay Mountains

The Finlay Limestone is slightly less than 200 feet thick in the Finlay Mountains, the type area, and the lithology is more complex than Richardson indicated. In the eastern part of the mountains, it consists of about 52 percent limestone, 46 percent marl, and 2 percent sandstone. Farther west, the formation is less marly and consists of about 74 percent limestone, 25 percent marl, and 1 percent sandstone. From the outcrops, however, one gains the impression that the formation is a massive limestone. Toward the top, several massive limestone beds form cliffs 10 to 20 feet high and make a caprock which is the only part of the sequence that is everywhere well exposed. The marly beds and thin-bedded limestones below the cap in most places are covered by rubble.

The following two measured stratigraphic sections illustrate the more marly and the less marly facies in the eastern and western parts of the Finlay Mountains. In neither is the top preserved, but the first section is the more complete and may be taken as the reference section.

SECTION 18.—*Reference section of the Finlay Limestone*

[Eastern part of Finlay Mountains, at conical hill in headwaters of Gardner Draw; traverse 18 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

	Thickness (feet)
Finlay Limestone (top not exposed):	
21. Limestone, yellowish-gray, fine-textured; weathers grayish orange. Contains abundant *Caprina* sp. as much as a foot long; shells and shell fragments make up about a third of the rock. Forms caprock along south border of Diablo Plateau and outlying mesas nearby	16.0
20. Marl, gray, sandy	13.0
19. Limestone, fine-textured, dark-gray; in beds 1 to 5 ft thick; nodular toward base	19.0
18. Marl, gray	12.0
17. Limestone, fine-textured, dark-gray, nodular	5.0
16. Marl, gray, grading upward into nodular limestone	7.0
15. Limestone, fine-textured, nodular, gray	4.0
14. Marl, gray; poorly exposed	22.0
13. Limestone, fine-textured, gray, nodular	6.0
12. Limestone, yellowish-gray, marly	10.0
11. Sandstone, light-brown, medium-grained, calcareous; grains subrounded; laminated rock containing trails and casts of invertebrates on bedding surfaces. Contains scattered fragments of oyster shells	3.0
10. Limestone, yellowish-gray, marly; breaks into irregular fragments. Contains *Pecten* sp. and *Exogyra texana* Roemer. Microfossils abundant; *Haplophragmoides globosus* Lozo, *Ammobaculites laevigatus* Lozo, and *Eponides* sp.—the most common foraminifers; *Bythocypris* sp. aff. *B. rotundus* Vanderpool, *Paracypris siliqua* Jones and Hinde, and *Cythereis* sp. aff. *C. nuda* (Jones and Hinde)—the most common ostracodes	26.0
9. Limestone, light olive-gray; weathers grayish orange. Contains *Exogyra texana* Roemer, numerous echinoid plates and spines, and arenaceous foraminifers, including *Ammobaculites* sp. aff. *A. humei* Nauss	.5
8. Marl, poorly exposed	12.0
7. Sandstone, very fine grained, grayish-orange pink; weathers light brown; cemented by calcium carbonate and quartz; laminated, partings 1 to 5 mm apart. Contains scattered shell fragments, echinoid spines, foraminifers and trails and casts of invertebrates	.5
6. Marl, gray to buff, interbedded with medium light-gray magnesian limestone. About half the limestone consists of fragments of gastropods and pelecypods and of arenaceous foraminifers (*Lituola*)	8.0
5. Limestone, fine-textured, medium-gray; weathers to light olive gray; nodular. Contains numerous shell fragments	7.0
4. Marl, gray. Contains abundant microfossils; *Ammobaculites laevigatus* Lozo and other lituolids—the most common foraminifers; *Cytheridea amygdaloides* var. *brevis* (Cornuel), *Cytheridea goodlandensis* Alexander, and *Cytheropteron tumidum* Alexander—the most common ostracodes	8.0

SECTION 18.—*Reference section of the Finlay Limestone*—Con.

Finlay Limestone (top not exposed)—Continued	*Thickness (feet)*
3. Sandstone, fine-grained, cross-laminated, quartzitic; very pale orange spotted with grayish orange; contains scattered grains of chert; in beds a fraction of an inch to 6 in. thick; oscillation ripples on bedding surfaces	2.0
2. Marl, gray. Contains abundant microfossils; *Ammobaculites subcretaceus* Cushman and Alexander and *Discorbis* sp. cf. *D. minima* Vieaux—the most common foraminifers; *Cytherella fredericksburgensis* Alexander and *Cytheridea* spp.—the most common ostracodes	9.0
1. Limestone, gray, sandy, grading into calcareous sandstone at base. Contains turritelliform gastropods	2.0
Total exposed thickness	192.0

Cox Sandstone.

SECTION 1.—*Section of the Finlay Limestone*

[Western Finlay Mountains, due west of Wilkie Ranch house; traverse 1 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

Finlay Limestone (top not exposed):	*Thickness (feet)*
26. Limestone, fine-textured, gray; contains numerous shell fragments	2.0
25. Unexposed; gentle slope covered with limestone fragments	2.0
24. Limestone, fine-textured, gray; contains abundant pelecypods and gastropods. Forms cap of cuesta	4.0
23. Limestone, nodular, gray; weathers to gentle slope. Contains *Tylostoma tumidum* (Shumard), *T. elevatum* (Shumard), *Nerinea* sp., *Protocardia texana* Conrad, and fragments of oysters (*Exogyra texana*? Roemer)	14.0
22. Limestone, fine-textured, gray; nodular, in four beds of about equal thickness, separated by undulating bedding planes; contains rudistids. Caps minor cuesta	7.0
21. Mostly unexposed; ledges of nodular gray limestone crop out in places	8.0
20. Limestone, fine-textured, laminated (in two beds separated by undulatory surface) light olive-gray; weathers pale yellowish brown. About half of rock consists of shell fragments, echinoid plates and spines, and microfossils. *Dictyoconus walnutensis* (Carsey) seen on weathered surfaces; *Coskinolinoides texanus* Keijzer and miliolid foraminifers in thin section	3.0
19. Limestone, nodular; poorly exposed	3.0
18. Limestone, light olive-gray, containing scattered cubes of pyrite and many fragments of pelecypod shells	3.0
17. Limestone, gray, nodular; poorly exposed, weathering to gentle slopes. Contains *Enallaster mexicanus* Cotteau, *Tylostoma tumidum* (Shumard), *T. elevatum* (Shumard), and *Cerithium diversecingulatum* Stanton	12.0
16. Limestone, pale yellowish-brown, fine-textured; weathers grayish orange; massive toward base, nodular toward top	13.0

SECTION 1.—*Section of the Finlay Limestone*—Continued

Finlay Limestone (top not exposed)—Continued	*Thickness (feet)*
15. Limestone, marly, white, soft and chalky, breaking with an earthy fracture. Contains *Enallaster mexicanus* Cotteau, *Tylostoma elevatum* (Shumard), and casts of large pelecypods. Abundant microfossils; *Barkerina barkerensis* Frizzell and *Ammobaculites laevigatus* Lozo—the most common foraminifers; *Bythocypris* spp., *Paracypris siliqua* Jones and Hinde, and *Cythereis* sp. aff. *C. nuda* (Jones and Hinde)—the most common ostracodes	20.0
(A sill of dark hornblende porphyry 7.5 ft thick occurs locally at this horizon.)	
14. Marl, brown, interbedded with dark-gray nodular limestone. Contains abundant microfossils; *Discorbis* and *Eponides*—the most common foraminifers; *Cytherella fredericksburgensis* Alexander and *Paracypris siliqua* Jones and Hinde—the most common ostracodes	12.0
13. Limestone, fine-textured, dark-gray	.5
12. Marl, gray, silty	6.0
11. Limestone, dark-gray, brown-weathering	2.0
10. Limestone, nodular, gray, interbedded with gray marl. Contains *Exogyra texana* Roemer, *Protocardia texana* Conrad, *Cardium*? sp., and *Lunatia*? *praegrandis* (Roemer)	3.0
9. Limestone, pale yellowish-brown, fine-textured, sandy; weathers yellowish gray; breaks conchoidally. Contains shell fragments and echinoid spines	.5
8. Marl, gray	.5
7. Limestone, gray; contains numerous shell fragments and arenaceous foraminifers	.5
6. Marl, gray	4.0
5. Limestone, nodular, gray	.5
4. Marl, silty, gray	1.0
3. Limestone, nodular, gray, containing *Exogyra texana* Roemer, *Gryphaea mucronata* Gabb, *Lunatia*? *pedernalis* (Roemer), and fragments of *Engonoceras*. Caps cuesta	33.0
2. Sandstone, very fine grained, calcareous, grayish-orange	1.0
1. Marl, sandy; poorly exposed	9.0
Total exposed thickness	165.0

Cox Sandstone.

Typical limestone of the Finlay is gray and contains 25 to 50 percent shells or shell fragments and 3 to 15 percent insoluble detrital matter, all set in a fine-textured carbonate matrix. Individual beds are 6 inches to 6 feet thick, and sequences of limestone beds are as much as 35 feet thick. Most of the limestone is massive, but some beds are internally laminated. Limonitic pseudomorphs after pyrite are common in many places.

All limestone beds examined are fossiliferous, some containing many whole clams, snails, and heart urchins. Other layers, seemingly nonfossiliferous, prove on microscopic examination to be rich in tiny shell fragments and tests of foraminifers and ostracodes. The fossils lie in a microcrystalline or cryptocrystalline carbonate matrix. Most of the longer shells and their fragments have been reconstituted as calcite mosaics, although some retain their original lamellar or prismatic structure. Presumably the matrix is also recrystallized and may also have been largely organic, representing an end product in the mechanical reduction of shells. The limestone must have originated as a shelly calcareous mud.

Chemical analyses of four typical specimens (Guerrero, 1952) shows that the calcium carbonate content ranges from 83.5 percent in a sandy limestone to 94.1 percent in a limestone with 3.3 percent detrital clay. Magnesium carbonate content ranges from slightly less than 1 percent to as much as 2.45 percent.

Where the insoluble detrital matter is quartz silt or sand, the limestone is firmly indurated and breaks with subconchoidal fracture. Where the insoluble fraction is largely clay, the limestone is chalky, breaks with earthy fracture, and weathers nodular. Both types of limestone are common. By increase of the sand content, the rock grades locally into calcareous sandstone, and by increase of the clay fraction, into marl.

The marl in the Finlay Limestone is typically a gray earthy rock in which the acid-insoluble fraction of clay, silt, and fine sand commonly equals or slightly exceeds the carbonate fraction. It is weakly indurated and weathers to gentle rubble-covered slopes or to recesses between limestone ledges; hence it generally is not well exposed. The marl forms beds ranging from partings half a foot across to massive layers as much as 10 to 20 feet thick. Marl is most common in the eastern part of the Finlay Mountains, where it is interbedded with limestone throughout the sequence. Farther westward, it is concentrated in the lower half of the formation.

The sandstone occurs only in the lower part of the formation, where it forms beds 6 inches to 3 feet thick. In the eastern part of the Finlay Mountains, three sandstone beds lie about 10, 35, and 75 feet above the base, but farther westward, only the lowest sandstone is present.

Except for differences in fossil content, the sandstone in the Finlay resembles that of the Cox. Freshly exposed surfaces are grayish orange and weather light brown. The texture ranges from very fine to medium grained. The most abundant constituents are quartz grains, chiefly subrounded to subangular. Accessory detrital minerals are lacking in most samples except for some scattered grains of chert. The grains are cemented by secondary growths of quartz, calcite, and in some places by limonite. Much of the sandstone is evenly laminated in layers 1 to 5 mm thick.

Trails and castings, presumably of invertebrates, are commonly visible on bedding surfaces. Fragments of oyster shells and echinoid plates and spines are ordinarily present, and some sandy beds contain abundant ostracodes and large arenaceous foraminifers.

Other localities

Along the spur of the Diablo Plateau directly west of Thaxton Spring, the Finlay Limestone is 170 to 175 feet thick. The overlying Kiamichi Formation is eroded, but thick limestone beds that here form the rimrock of the plateau appear to be the same as those that cap the Finlay in the type area. In the Thaxton Spring area, the Finlay consists of 96 percent limestone and 4 percent sandstone. More than half of the limestone contains enough clay to give the rock an earthy cast and a nodular appearance on weathered surfaces, but there are no beds of soft silty marl. Gray nodular limestone, in layers 10 to 25 feet thick, is interbedded with thinner layers of fine sandstone and hard, fine-textured gray limestone. The rimrock at the top of the section is 36 feet of hard gray limestone in beds a few inches to several feet thick; fossils make up much of the hard ledges of limestone in the rimrock.

Steeply dipping beds of Finlay Limestone form the crest of Campo Grande Mountain and extend in low hogbacks along its north edge. Across the northern belt of outcrop the formation is at least 235 feet thick, or about 45 feet thicker than the beds preserved at the type area. The exposed parts are all limestone. In the lower 75 feet it is mostly gray, argillaceous, and nodular; higher up it is harder and less argillaceous. Sets of limestone beds range from 5 to 45 feet in thickness. A conspicuous hard limestone layer 40 feet thick at the top of the section is presumably the same one that forms the rimrock of the Diablo Plateau and marks the approximate upper surface of the formation in this region. A conspicuous layer of sandy limestone occurs 75 feet above the base; it is finely laminated and olive gray and contains 20 percent very fine sand. Only about two-thirds of the Finlay is well exposed, and many intervals 8 to 16 feet thick are concealed in the upper part. If the concealed units are marl, the proportion of limestone to marl in the entire section would have a ratio of about 2:1, which is intermediate between the ratios of limestone to marl in the eastern and in the western parts of the Finlay Mountains.

Gently dipping beds of Finlay Limestone extend over most of the Diablo Plateau in the report area, and rudistid-bearing limestone beds near the top of the formation cap the mesas.

Sand content of the formation increases northeastward across the plateau, partly by increase of sand in limestone and partly by increase in number of sandstone beds and lenses. North of the Sierra Blanca area the entire formation grades into sandstone. The sandstone is white, brown, and red and weathers brown. It occurs in small lenses and as beds 10 to 12 feet thick that can be traced for several miles. The most conspicuous beds are separately mapped (pl. 1). The quartz grains are subangular to rounded and fine to coarse and have a calcareous cement. Limonite coats many grains and stains the sandstone irregularly, as in the underlying Cox Sandstone. The sandstone is evenly bedded or crossbedded and locally ripple marked and in places fills channels cut into limestone. Although incompletely exposed, the Finlay Limestone appears to have a maximum thickness of about 160 feet on the Diablo Plateau and to be 100 to 130 feet thick at the north edge of the mapped area.

Along the southwest side of Devil Ridge and the east side of the Quitman Mountains, the Finlay is all limestone except for about 5 feet of sandstone on Devil Ridge and some interbeds of marl (pl. 4). Gray limestone beds are 1 to 5 feet thick and form ledges or low bluffs separated by thin soft marly beds. The Finlay is 346 feet thick on Yucca Mesa (section 6, pl. 4) and 510 feet thick in the southern part of the Quitman Mountains.

RELATION TO COX SANDSTONE

The Finlay Limestone is conformable and gradational with the underlying Cox Sandstone. Along Devil Ridge and the southern part of the Quitman Mountains, the lithologic break between the two formations is abrupt; sandstone occurs below and limestone above. In the Finlay Mountains and the Diablo Plateau, however, there is generally a transition zone 30 to 40 feet thick in which the calcareous and the siliceous rocks of the two formations blend or alternate. Here we have placed the contact of the horizon that separates predominant sandstone below from limestone or marl above.

The Finlay Limestone evidently intergrades laterally and interfingers with the Cox Sandstone eastward and northward from the reference section of the Finlay (pl. 5). Beds cannot be traced along the contact from north to south, but the changes between limestone and sandstone in the Diablo Plateau indicate that most, if not all, of the northward thinning of the Finlay is due to the gradation from limestone to sandstone and to the interfingering of the two rock types. The Finlay and Cox are thus lithologic units which transgress time boundaries and are partly equivalent in age.

FOSSILS

The Finlay Limestone is fossiliferous from bottom to top. The following discussion of the Finlay fauna from the Finlay Mountains is based on two groups of collections, one made by C. C. Albritton, Jr., and W. O. Ham for the museum at Southern Methodist University and the other by us and our associates for the U.S. Geological Survey. All the fossils were collected incidentally to the measuring of stratigraphic sections and without special effort to find localities where fossils might be exceptionally well preserved. Fifty species of marine invertebrates have been identified, but at least 60 additional species must be represented among the fragments and imperfect specimens. Except as indicated otherwise, the fossils were identified by Albritton.

Pelecypods and gastropods are the most abundant megafossils. Most of the pelecypods are large and thick shelled; oysters and pachyodonts are especially common. Contorted tubes of the marine worm, *Serpula*, cover many of the oyster shells. Gastropods are numerous and varied, small and large, turreted and low spired, but most of them weather from the rock as internal molds that are difficult or impossible to identify.

Echinoids abound at certain horizons, their broken spines and plates commonly forming a large part of the residue of washed samples. Branching corals are embedded in some of the upper ledges of hard limestone, and *Ceratotrochus*, a small solitary coral, was found in float that must have come from the lower 100 feet of the formation. Although a special search was made for ammonites, only two fragments of *Engonoceras* were found, both in float from near the base of the formation.

Microfossils are abundant. Some of the foraminifers, such as *Lituola* and *Dictyoconus* (fig. 40), are

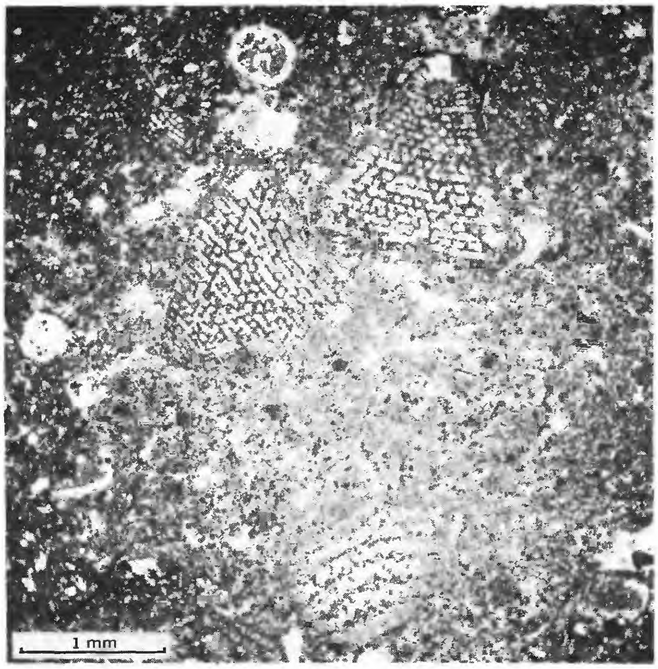

FIGURE 40.—Finlay Limestone from Gunsight Hills, showing section through the large foraminifer, *Dictyoconus walnutensis* (Carsey).

large enough to be visible on the outcrop, and a variety of smaller tests appear in washed samples of marl and sandstone. Ostracodes are invariably associated with the foraminifers.

Finlay Mountains

Foraminifers.—Among the 1,360 tests of Foraminifers mounted in the collections at Southern Methodist University are representatives of 13 families, 42 genera, and at least 55 species. As all of these were taken from only six washed samples, and as all six samples came from the lower half of the formation, the check list that follows probably includes only part of the whole fauna.

Gastropods—*Lunatia? pedernalis* (Roemer), *Tylostoma tumidum* (Shumard), and *T. elevatum* (Shumard) occur through the entire thickness of the formation and are abundant at most horizons. *Lunatia? praegrandis* (Roemer), *Neritina? elpasensis* Stanton, *Tylostoma regina* (Cragin), *Cerithium bosquense* Shumard, and *Nerinea kerrvillensis* Stanton are less common and have been found only in the lower half of the formation. *Cerithium diversecingulatum* Stan-

Check list of Foraminifera from the Finlay Limestone of the Finlay Mountains and adjoining Diablo Plateau

[Figures show relative abundance of species as percentage of total population in each sample. Identifications by C. C. Albritton, Jr.]

Families, genera, and species arranged taxonomically	Locality and horizon						
	Diablo Plateau; spur west of Thaxton Spring; basal 6 ft	Eastern Finlay Mountains; unit 2, section 18	Eastern Finlay Mountains; unit 4, section 18	Eastern Finlay Mountains; unit 9, section 18	Eastern Finlay Mountains; unit 10, section 18	Western Finlay Mountains; unit 14, section 1	Western Finlay Mountains; unit 15, section 1
LITUOLIDAE							
Trochamminoides sp. aff. *T. coronus* Loeblich and Tappan						0.87	
Haplophragmoides globosus Lozo		5.58	2.39		13.88	1.31	3.81
Haplophragmoides? sp					1.98	.87	.27
Barkerina barkerensis Frizzell and Schwartz		.55					20.16
Ammomarginulina sp						1.31	
Ammobaculites goodlandensis Cushman and Alexander					.79		
sp. aff. A. *humei* Nauss				[1] 90.00			
laevigatus Lozo		3.91	67.94		29.36	.43	46.32
subcretaceus Cushman and Alexander		16.75	3.34		.39	4.80	
Flabellammina alexanderi Cushman						1.74	.54
Triplasia goodlandensis Cushman and Alexander			.47			.43	
sp							1.08
Buccicrenata subgoodlandensis (Vanderpool)	67.54	.55	3.82				
Lituola subgoodlandensis (Vanderpool)	30.70	3.91	2.87		5.15	.87	1.90
TEXTULARIIDAE							
Ammobaculoides whitneyi (Cushman and Alexander)		1.67					
VERNEUILINIDAE							
Verneuilinoides schizeus (Cushman and Alexander)		1.11				1.31	2.17

See footnotes at end of table.

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Check list of Foraminifera from the Finlay Limestone of the Finlay Mountains and adjoining Diablo Plateau—Continued

Families, genera, and species arranged taxonomically	Locality and horizon						
	Diablo Plateau; spur west of Thaxton Spring; basal 6 ft	Eastern Finlay Mountains; unit 2, section 18	Eastern Finlay Mountains; unit 4, section 18	Eastern Finlay Mountains; unit 9, section 18	Eastern Finlay Mountains; unit 10, section 18	Western Finlay Mountains; unit 14, section 1	Western Finlay Mountains; unit 15, section 1
VALVULINIDAE							
Cuneolina sp		.55					
Coskinolinoides texanus Keijzer		1.67					4.90
Dictyoconus walnutensis (Carsey)[2]							
MILIOLIDAE							
Quinqueloculina triangulata Stead	.87	5.02	4.30		6.34		4.08
Triloculina meotica Loeblich and Tappan		1.11	4.78		.39		
sp		5.58					
OPHTHALMIDIIDAE							
Ophthalmidium minimum Tappan		2.79					
Ophthalmidium ? sp					1.19		2.45
TROCHAMMINIDAE							
Trochammina sp							.27
LAGENIDAE							
Lenticulina aff. *L. gaultina* (Berthelin)						.43	
Marginulina spp		.55			.39		1.08
Dentalina communis (d'Orbigny)						.43	
cucumis Loeblich and Tappan		1.11					
sp		1.67					
Nodosaria aff. N. *graysonensis* Tappan		.55					
Pseudoglandulina scotti Tappan		1.67					
sp. aff. P. *mutabilis* (Reuss)					.39		.27
Lingulina furcillata Berthelin						.43	
sp		3.91					
Vaginulina sp		.55					
Citharina intumescens (Reuss)		.55					.27
Palmula sp. aff. *P. leai* Loeblich and Tappan							.27
POLYMORPHINIDAE							
Eoguttulina? sp		1.11					
Paleopolymorphina sp			.95		2.38		1.08
Guttulina symploca Loeblich and Tappan			.47				.54
sp		.55					
Globulina exserta (Berthelin)		7.82	.47		1.19	3.93	
aff. G. *exserta* (Berthelin)							1.36
Pseudopolymorphina plectilis Loeblich and Tappan						.87	.54
aff. *P. roanokensis* Tappan		2.23				.87	
Ramulina spp		9.49	1.43		1.98		2.99
BULIMINIDAE							
Neobulimina minima Tappan			1.43		.79		
Bolivina sp					.39		
ROTALIIDAE							
Patellina subcretacea Cushman and Alexander		.55					
Discorbis floscula Loeblich and Tappan		1.67	1.91	[1] 10.00		6.98	1.36
cf. *D. minima* Vieaux		10.61	2.87		.39	32.31	.54
Discorbis? sp		1.11					
Valvulineria sp	.87	1.11			3.17	.43	1.63
Eponides sp. aff. *E. ingramensis* Cushman and Goudkoff		2.23			28.96	37.99	
Eponides? sp			.47			.87	

See footnotes at end of table.

Check list of Foraminifera from the Finlay Limestone of the Finlay Mountains and adjoining Diablo Plateau—Continued

Families, genera, and species arranged taxonomically	Locality and horizon						
	Diablo Plateau; spur west of Thaxton Spring; basal 6 ft	Eastern Finlay Mountains; unit 2, section 18	Eastern Finlay Mountains; unit 4, section 18	Eastern Finlay Mountains; unit 9, section 18	Eastern Finlay Mountains; unit 10, section 18	Western Finlay Mountains; unit 14, section 1	Western Finlay Mountains; unit 15, section 1
GLOBIGERINIDAE							
Globigerina cf. G. *washitensis* Carsey						.43	
ANOMALINIDAE							
Anomalina? sp					.39		
Total number of tests taken from sample	114	179	209	10	252	229	367

[1] From acid-insoluble residue; percentages, not significant.
[2] Not found in washed samples, but abundant in limestone in upper half of formation.

ton and *Nerinea* sp. cf. *N. texana* Roemer are both fairly common in the upper half of the section but were not found in the lower.

Pelecypods.—*Exogyra texana* Roemer is abundant at various horizons from bottom to top of the Finlay Limestone. Single valves are more common than whole shells, and many specimens appear to have been worn or broken before they were buried. Other types of oysters are comparatively rare, although specimens of *Ostrea crenulimargo* Roemer and *Gryphaea mucronata* Gabb occur in places in the lower half of the formation.

The scallops (pectens) are almost as abundant as the oysters. Most of them are small, measuring less than an inch across, and are preserved as single valves or fragments which cannot be positively identified. A larger but less common species in the lower half of the formation closely resembles *Pecten duplicicosta* Roemer.

Protocardia texana Conrad is the only other clam which occurs in large numbers throughout the formation. *P. multistriata* Shumard, a smaller and more finely striate shell, is fairly common in the lower half.

Pachyodonts are abundant in the upper half of the formation, especially in the ledges of hard limestone near the top. *Caprina* sp. cf. *C. occidentalis* Conrad, *Toucasia texana* (Roemer), and *Radiolites* sp. are the most common.

Many of the pelecypods in the lower half of the sections are preserved as casts, molds, or fragments which cannot be certainly identified. These include at least one species each of *Trigonia*, *Cyprimeria*, and *Homomya*, three of *Lima*, and three whose generic affinities are in doubt but which have been referred provisionally to *Tapes*, *Cardium*, and *Sphaera*.

Ostracodes.—The same six samples that yielded 1,360 tests of foraminifers contained 652 carapaces of ostracodes. In five of these samples, foraminifers were between two and six times as numerous as ostracodes, but in one sample the ostracodes outnumbered the foraminifers. The ratio of ostracodes to foraminifers seems to be higher in beds of silty marl than in beds of marly limestone and lowest in the sandstone toward the base of the formation.

Collections at Southern Methodist University contain at least 22 species, of which about half have not yet been described. The list on page 78 shows the relative abundance of the various kinds in the samples examined.

Echinoids.—The heart urchin *Enallaster mexicanus* Cotteau occurs throughout the Finlay Limestone and is the only abundant echinoid. *Holectypus planatus* Roemer is associated with *Enallaster* in the lower half of the formation but was not found in the upper half. *Tetragramma*, represented by at least two species, occurs sparsely throughout; *T. malbosii* (Agassiz) was identified by C. Wythe Cooke from collections in float near the base.

Other localities

In the Thaxton Spring area, sandy beds in the lower part of the formation contain many microfossils. Of 114 tests of foraminifers picked from a layer of calcareous sandstone 5 feet above the top of the Cox Sandstone, about 67 percent are *Buccicrenata subgoodlandensis* (Vanderpool), and 31 percent are *Lituola subgoodlandensis* (Vanderpool). The associated ostracodes, which are less abundant, include *Paracypris siliqua* Jones and Hinde and "*Cythere*" *concentrica* (Reuss). Fossils make up a large part of the hard ledges of limestone in the rimrock in this area. The gastropods, represented by a varied assemblage including *Lunatia*? *pedernalis* (Roemer) and *Nerinea* sp. cf. *texana* Roemer, are probably the most abundant, but *Caprina* and other pachyodonts also

Check list of ostracodes from the Finlay Limestone of the Finlay Mountains and adjoining Diablo Plateau

[Figures show relative abundance of species as percentage of total population in each sample. Identifications by C. C. Albritton, Jr.]

Genera and species	Locality and horizon					
	Diablo Plateau spur west of Thaxton Springs; basal 6 ft	Eastern Finlay Mountains; unit 2, section 18	Eastern Finlay Mountains; unit 4, section 18	Eastern Finlay Mountains; unit 10, section 18	Western Finlay Mountains; unit 14, section 1	Western Finlay Mountains; unit 15, section 1
Bairdia aff. *B. comanchensis* Alexander	----------	----------	----------	1. 32	0. 99	7. 14
Bairdia? sp	----------	----------	----------	----------	. 99	. 79
Bythocypris goodlandensis Alexander	----------	4. 58	7. 46	6. 58	2. 97	7. 94
aff. *B. rotundus* Vanderpool	----------	14. 88	----------	15. 79	2. 97	3. 97
sp	----------	1. 52	----------	5. 26	----------	11. 90
Cytherella fredericksburgensis Alexander	----------	16. 41	2. 99	3. 95	60. 40	5. 55
scotti Alexander	----------	1. 52	1. 49	5. 26	2. 97	7. 94
Paracypris siliqua Jones and Hinde	5. 00	6. 87	1. 49	15. 79	8. 91	9. 52
Cytherelloidea sp	----------	. 38	----------	----------	----------	5. 55
"*Cythere*" *concentrica* (Reuss)	10. 00	1. 91	1. 49	1. 32	1. 98	4. 76
Cythereis carpenterae Alexander	----------	4. 96	----------	1. 32	2. 97	----------
worthensis Alexander	----------	6. 11	8. 96	1. 32	----------	----------
aff. *C. nuda* (Jones and Hinde)	5. 00	1. 14	1. 49	14. 47	----------	19. 05
aff. *C. sandidgei* Alexander	----------	. 76	----------	9. 21	5. 94	7. 14
Cytheridea amygdaloides var. *brevis* (Cornuel)	----------	. 76	32. 83	----------	----------	----------
goodlandensis Alexander	----------	----------	11. 94	1. 32	----------	----------
oliverensis Alexander	----------	----------	----------	5. 26	----------	5. 55
spp	80. 00	29. 39	10. 45	----------	----------	----------
Cytherura sp	----------	5. 72	1. 49	3. 95	1. 98	----------
Cytheropteron tumidum Alexander	----------	3. 05	16. 42	7. 89	----------	2. 38
spp	----------	----------	1. 49	----------	2. 97	. 79
Metacypris sp	----------	----------	----------	----------	3. 96	----------
Total number of carapaces taken from sample	20	262	67	76	101	126

occur in large numbers. *Exogyra texana* Roemer, *Lima* sp. aff. *L. blancensis* Stanton, and small pectens are also present, and fragments of the echinoid *Tetragramma* are fairly common. Heads of branching corals occur in some places, although the corals must have been far less important as rock builders than the shellfish.

Fossils are abundant in the Finlay at Campo Grande Mountain but weather from the rock mostly as fragments. *Exogyra texana* Roemer is common in beds of nodular limestone toward the base, where it is associated with *Cyprimeria* and other pelecypods.

Many beds on the Diablo Plateau are fossiliferous. *Dictyoconus*-bearing beds are common in places, and rudistid limestone caps numerous low mesalike hills. R. W. Imlay (written communication, 1950) identified a collection (USGS Mesozoic loc. 21071) from 54 to 82 feet below the Kiamichi(?) Formation in the northeastern part of the mapped area as: *Exogyra texana* Roemer, *Trigonia* sp., *Protocardia texana* Conrad, *Protocardia* sp., *Protocardia multistriata* Shumard, *Cardium*? cf. *C. subcongestum* Böse, *Cyprimeria* sp., *Neithea occidentalis* Conrad, *Brachydontes* sp., *Volsella concentrice-castallata* Roemer, *Sphaera* cf. *S. roblisi* (Böse), *Tapes*? sp., *Nerita*? cf. *N. elpasensis* Stanton, *Tylostoma* sp., *Gyrodes*? sp., *Aporrhais*? sp., *Monodonta*? sp., *Cerithium*? cf. *C.*? *pecosense* Stanton, and *Turritella seriatim-granulata* Roemer.

Along Devil Ridge and the southern part of the Quitman Mountains, most of the limestone is fossiliferous, but many of the fossils are poorly preserved. *Dictyoconus* abounds in the upper half of the formation, and rudistids form a major part of some beds. Fossils collected along Devil Ridge have been listed by Smith (1940, p. 615).

AGE AND CORRELATION

The Finlay Limestone is clearly of Fredericksburg age, although it once was considered part of the Trinity Group (Baker, 1927, p. 21). In some respects this formation is similar to the Edwards Limestone many miles to the east, and it may be equivalent to the Edwards.

The Finlay fauna in the type area is generally like that of the lower part of the Fredericksburg Group elsewhere and is particularly like the faunas of the Walnut Clay and Goodland Limestone in northern Texas.

Of the 27 species of foraminifers identified, 20 have been reported previously from the Walnut and 15, from the Goodland. *Ammobaculoides whitneyi* (Cushman and Alexander), *Dentalina cucumis* Loeblich and Tappan, *Citharina intumescens* (Reuss), and *Pseudo-*

polymorphina plectilis Loeblich and Tappan, which occur in the Finlay, are all restricted to the Fredericksburg Group farther eastward in Texas. Also, *Dictyoconus walnutensis* (Carsey) (formerly *Orbitolina*), a species widespread in the Finlay, is characteristic of the Fredericksburg (H. J. Plummer, in Smith, 1940, p. 615; and Lynch, 1933, p. 111), although its range extends downward into the Trinity Group (Frizzell, 1954, p. 76).

All gastropod species that are abundant in the Finlay Limestone are well known in the Fredericksburg Group elsewhere. *Tylostoma tumidum* (Shumard) has been reported only from this group elsewhere in Texas. *Turritella seriatum-granulata* Roemer is known from Edwards Limestone and from the Kiamichi Formation, both of the Fredericksburg Group, but not from the Glen Rose of the Trinity Group. Among the less common species, *Neritina? elpasensis* Stanton, *Cerithium bosquense* Shumard, *Nerinea kerrvillensis* Stanton, and *Cerithium diversecingulatum* Stanton are also probably restricted to the Fredericksburg.

Pelecypods most common in the Finlay Limestone, however, appear to have long stratigraphic ranges. Massive rudistid beds in the Finlay are similar to those in the Edwards Limestone, but identification of the rudistids is not positive enough for use in correlation.

Ten of the eleven species of ostracodes identified from the Finlay have also been previously reported from the Goodland Limestone. *Bythocypris goodlandensis* Alexander, *Cytherella scotti* Alexander, and *Cytheridea goodlandensis* Alexander are possibly restricted to the Goodland in northern Texas, and *Cytherella fredericksburgensis* Alexander, *Cytheridea oliverensis* Alexander, *Paracypris siliqua* Jones and Hinde, and "*Cythere*" *concentrica* (Reuss), although not confined to the Goodland, are most abundant in it (Alexander, 1929).

Among the echinoids, *Holectypus planatus* Roemer occurs both in the Trinity and the Fredericksburg Groups, but *Tetragramma malbosii* (Agassiz) and *Enallaster mexicanus* Cotteau are characteristic of the Fredericksburg (Cooke, 1946, p. 207; 1955, p. 104).

CONDITIONS OF DEPOSITION

The Finlay Limestone was deposited as calcareous mud and sand in a shallow sea that covered the entire Sierra Blanca area. The more sandy sediments in the north accumulated nearer the shore than the calcareous sediments to the south, but the two are largely contemporaneous. The environment of deposition remained fairly uniform during Finlay time, and conditions were generally favorable for flourishing populations of marine shellfish. The abundant benthonic foraminifers and echinoderms and their association with varied shellfish, ostracodes, and, in places, with stony corals indicate marine deposition. Only two elements of the usual Cretaceous marine fauna are lacking—planktonic foraminifers and ammonites.

Scarcity of planktonic tests in an otherwise diversified assemblage of foraminifers might mean that the sea water near the bottom was normally saline but that the salinity of the water near the surface was below the limit of tolerance for planktonic species. Such conditions resemble those off the delta of the Mississippi River in the Gulf of Mexico, where Lowman (1949, p. 1954–1955) found few remains of *Globigerina* and other floating foraminifers among the tests accumulated on bottoms shallower than about 60 feet. More recent studies by Phleger (1955) suggest that the absence of planktonic tests in sediment beneath the sounds around the delta may ultimately be due to the low salinity of an upper layer of sea water diluted by fresh water from the Mississippi River and other streams. Ancient streams likewise may have diluted the upper parts of the Finlay sea in areas near shore and thus permitted a marine fauna to flourish beneath the heavier and more saline water at depth and at the same time prevented the planktonic foraminifers from populating the upper less saline levels.

If most of the Early Cretaceous ammonites were swimmers that inhabited upper waters of the sea, they may, like the globigerinids, have been adversely affected by near-shore zones of brackish water, a condition that accounts for their scarcity.

Deposition of the Finlay commenced with spreading of the sea over sandy and presumably deltaic deposits of Cox Sandstone. In the area of the Finlay Mountains, the initial sea may not have been more than a few feet deep, as suggested by the abundance of agglutinated tests of foraminifers in some of the basal sandy limestone beds; such deposits resemble the *Ammobaculites* facies of lagoons east of the Mississippi delta (Phleger, 1954). The presence of abundant ostracodes and of miliolids, however, and the variety of calcareous tests suggest an open gulf rather than a sound or lagoonal environment. As the shoreline advanced northward, the water of the Finlay Mountains area probably deepened, although not necessarily to more than a few fathoms. Toward the end of Finlay time, when relatively little detrital sediment was accumulating, colonial corals and large sedentary clams grew in profusion along the bottom.

KIAMICHI FORMATION

DEFINITION AND GENERAL FEATURES

The Kiamichi Formation was named for the Kiamichi River in southeastern Oklahoma, where it was first called the Kiamitia Clays (Hill, 1891, p. 504, 515). The name, taken from a distant type area, was introduced into the Sierra Blanca region by Baker (1927, p. 28–30) and by Adkins (1932, p. 352–355). This use of Kiamichi in the mapped area seems justified on the basis of the formation's stratigraphic position and the general similarity of its fossils and lithology to the Kiamichi much farther east in Texas and Oklahoma.

The Kiamichi is preserved in several areas in the southern part of the Quitman Mountains, near Sierra Blanca peaks, and in the northeastern corner of the report area. The only complete section is in the Quitman Mountains. In the southern part of these mountains, the Kiamichi is less resistant to erosion than either the underlying Finlay or the overlying beds of Washita age and occurs on gentle slopes covered with float, but it is locally exposed in very steep slopes beneath overhanging cliffs. On the hills at the northwest end of Flat Mesa and on the Diablo Plateau, sandstone beds assigned to the Kiamichi stand in relief as ledges or form a caprock.

LITHOLOGY AND THICKNESS

In the south half of the Sierra Blanca area the Kiamichi is mostly shale, and in the north half, mostly sandstone.

In the Quitman Mountains, shale makes up most of the lower 140 feet of the formation, but in the upper 95 feet it is interbedded with an equal amount of limestone. Fine-grained sandstone is interbedded with the other rocks, most abundantly in the upper and more calcareous part. All of the formation is thin bedded, the sandstone and limestone being in layers generally 1 to 3 inches thick and the shale in layers slightly less than a foot thick. Sets of evenly bedded sandstone layers are as much as several feet thick. The limestone is lumpy and marly; the shale is commonly sandy or calcareous; and the sandstone is slightly calcareous. The rocks are prevailingly gray, but many of the sandstone beds weather light brown. Most of the formation is fossiliferous, especially the upper part.

Near Flat Mesa, the Kiamichi Formation consists mostly of sandstone but contains a few beds of sandy clay. Most of the sandstone is light tan to white and weathers to shades of brown, but some beds are light gray or purple. It consists of fine- to medium-sized angular to well-rounded quartz grains set in a ferruginous and calcitic cement and forms 1- to 3-foot beds, some of which are continuous through the exposures, whereas others thin and end within a few feet. Much of the sandstone is crossbedded, as shown on weathered surfaces of the harder and less calcareous beds. A sandstone bed 16 feet thick lies at the top of the formation and forms a prominent bluff along the north end of Flat Mesa.

SECTION 22.—*Section of Kiamichi Formation*

[In the southern part of the Quitman Mountains, about 3¼ miles east-southeast of Quitman Gap; traverse 22 shown on pl. 1]

	Thickness (feet)
Rocks of Washita age—Kiamichi Formation:	
3. Sandstone, light-tan to light-gray, fine-grained, slightly calcareous; weathers brown; some interbeds of shale, marl, and nodular limestone. Many beds are fossiliferous	49
2. Limestone, gray, nodular, interbedded with gray shale and tan fine-grained sandstone; sandstone and limestone beds generally 1 to 3 in. thick; shale beds as much as 1 ft thick	47
1. Shale, gray; some thin beds, 1 to 3 in., of gray nodular limestone, sandstone, and marl. All poorly exposed	139
Total measured thickness	235
Finlay Limestone.	

SECTION 23.—*Section of the Kiamichi Formation*

[Northwest end of Flat Mesa; traverse 23 shown on pl. 1. Fossil identifications by C. C. Albritton, Jr.]

	Thickness (feet)
Kiamichi Formation (top eroded):	
7. Sandstone, light-gray to almost white, calcareous, medium-grained; weathers light gray; stringers of less calcareous beds weather brown, protrude on weathered surface and contain some small scale crossbeds. Forms bluff at cap of hill	16
6. Sandstone, gray and tan, fine-grained; interbedded hard and friable layers; some friable light-purple beds	23
5. Unexposed; probably sandy clay	9
4. Clay, brown, sandy, and thin fine-grained sandstone lentils; calcareous, particularly in upper part. Numerous fragments of *Gryphaea*; fossils mostly small; *Gryphaea navia* Hall in thin sandy limestone within 10 ft of top. Unit poorly exposed	41
3. Unexposed; probably friable sandstone	29
2. Sandstone, light-tan, fine-grained (quartz grains), crossbedded; weathers brown	2
1. Sandstone, gray, fine-grained, calcareous, fossiliferous; poorly exposed on slope of loose rubble. Fossils, mostly large, weather out on surface	15
Total measured thickness	135
Finlay Limestone.	

In the northeastern part of the area, only 34 feet of the Kiamichi(?) Formation is preserved, and exposures are poor. Nearly all of it consists of white to brown sandstone that weathers brown or reddish brown and is made up of subangular to rounded medium-sized quartz sand grains set in a cement of calcite and limonite. Numerous botryoidal limonitic concretions, ½ to 3 inches across, are scattered through the formation. Beds are 1 to 3 feet thick and are evenly stratified in most places, although some small-scale ripple marks are present. Lentils of calcareous sandstone and gray nodular limestone 3 to 5 inches thick are traceable for as much as 15 feet laterally. Some layers contain molds and casts of pelecypods and gastropods and impressions of plant fragments.

The Kiamichi is about 235 feet thick in the Quitman Mountains in the report area, and Baker (1927, p. 38) reported 300 feet near the south end of the range, 15 miles farther south. At the north end of Flat Mesa, 135 feet of the formation is exposed; although the top is missing, the total thickness is probably no more than 200 feet.

The Kiamichi thus thins northward although not as rapidly as the older formations. Rocks of Kiamichi age occur at Sierra Prieta 7 miles northeast of the report area (Adkins, 1932, p. 354; King and Knight, 1944) but are not recognized as a separate lithologic unit.

RELATION TO FINLAY LIMESTONE

The gray shale of the Kiamichi and the limestone of the underlying Finlay are sharply separated but conformable in the southern part of the Quitman Mountains. Near Flat Mesa and in the northeastern part of the report area, the sandstone of the Kiamichi likewise abruptly but conformably succeeds the Finlay.

FOSSILS

The following fossils from the upper 95 feet of the Kiamichi Formation in the southern part of the Quitman Mountains (USGS Mesozoic loc. 21072) were identified by R. W. Imlay.

Gastropods.—Turritella seriatim-granulata Roemer, *Tylostoma regina* (Cragin), *Tylostoma elevatum* (Shumard), *Aporrhais?* sp., *Neritina? elpasensis* Stanton.

Pelecypods.—Exogyra texana Roemer, *Cyprimeria* sp., *Protocardia texana* Conrad, *Protocardia multistriata* Shumard, *Sphaera* cf. *S. roblesi* (Böse), *Trigonia* sp., *Lima* (*Plagiostoma*) sp., *Neithea occidentalis* Conrad, *Tapes?* spp., *Homomya bravoensis* Böse, *Cardita?* sp., *Pteria?* sp., *Pinna* sp., *Pecten* (*Syncyclonema*) sp.

Cephalopods.—Oxytropidoceras trinitense (Gabb), *O. acutocarinatum* (Shumard), *O. belknapi* (Marcou), *Engonoceras* cf. *E. pierdenale* (Von Buch).

A collection from the same part of the formation about 3 miles to the southeast was identified by C. C. Albritton, Jr., as follows:

Gastropod.—Tylostoma kentense Stanton.

Pelecypods.—Protocardia texana Conrad? *Protocardia* sp., *Tapes* sp., *Homomya* sp.

Brachiopod.—Kingena wacoensis (Roemer).

Cephalopod.—Oxytropidoceras belknapi (Marcou).

Echinoids.—Pliotoxaster whitei (Clark), *Tetragramma streeruwitzi* (Cragin), *Tetragramma taffi* (Cragin)?, *Salenia prestensis* Desor, *Macraster* spp. (large species). This collection is characterized by an abundance of echinoids.

From sandstone beds in the Kiamichi(?) Formation in the northeastern part of the Sierra Blanca area (USGS Mesozoic loc. 21070), R. W. Imlay identified:

Gastropods.—Turritella seriatum-granulata Roemer, *Cerithium?* sp.

Pelecypods.—Ostrea sp., *Exogyra texana* Roemer, *Neithea* sp., *Pecten* (*Syncyclonema*) sp., *Nucula* sp., *Nuculana?* sp., *Cardium* cf. *C. congestum* Böse, *Cardium?* sp., *Trigonia emoryi* Conrad, *Protocardia* sp.

Cephalopod.—Engonoceras cf. *E. pierdenale* (Von Buch).

From the Kiamichi at the north end of Flat Mesa, Adkins (1932, p. 352) collected and identified the following: *Gryphaea navia* Hall, *Gryphaea corrugata* Say, *Exogyra texana* Roemer, *Exogyra plexa* Cragin, *Alectryonia* cf. *carinata* Lamarck, *Alectryonia quadriplicata* (Shumard), *Pecten subalpinus* Böse, *Pecten irregularis* Böse, *Trigonia emoryi* Conrad, *Pholadomya* cf. *sancti-sabae* Roemer, *Protocardia*, *Plicatula incongrua* Conrad, *Turritella*, *Tylostoma*, *Parasmilia*, *Parasmilia?*, *Haplostiche* sp.?, *Oxytropidoceras belknapi* (Marcou), *Oxytropidoceras* n. sp., *Idiohamites fremonti* Marcou, *Hamites* aff. *comancheanus* Adkins and Winton, and *Pervinquieria* sp. (of the *nodosa* group).

AGE AND CORRELATION

The question of whether the Kiamichi Formation belongs in the Fredericksburg Group or in the Washita Group has been debated almost since the formation was named by Hill in 1891. Without tracing the history of the differences, evidence that disagreement still exists is demonstrated in a recent publication of the University of Texas in which the Kiamichi is variously shown to have Fredericksburg and Washita paleontologic affinities (Lozo, 1959, fig. 2), to be post-Fredericksburg (Lozo, 1959, fig. 10), to be in the Washita Group (Nelson, 1959, fig. 13), and to be in the Fredericksburg Group (Shelburne, 1959).

In the Sierra Blanca area, paleontologic evidence suggests that most, but not necessarily all, of the Kiamichi is of Fredericksburg age. Fossils from the southern part of the Quitman Mountains indicate that at least the lower part of the Kiamichi there is of Fredericksburg age. Fossils from incomplete sections in the north half of the report area are also of Fredericksburg aspect. *Oxytropidoceras belknapi* (Marcou), a characteristic fossil of the Kiamichi, has not been reported above the Fredericksburg Group, and yet another Kiamichi fossil, *Tetragramma streeruwitzi* (Cragin), probably is of Washita age (Smiser, 1933, p. 126, 138; 1936, p. 457). Because certain species of *Oxytropidoceras* and *Tetragramma* are found in the same beds in the Sierra Blanca area, it is possible that the Fredericksburg and Washita faunas overlap in this area and that the transitional zone is in the Kiamichi Formation.

CONDITIONS OF DEPOSITION

The Mesozoic sea covered all the report area during deposition of the Kiamichi, although conditions differed enough from north to south across the area for the grain size of the sediments to become finer southward. The sandstones from Flat Mesa northward suggest deposition on an open shelf. Finer grained beds to the south suggest deposition on the same shelf in quieter water farther from the shore. The sequence of rocks in the southern part of the Quitman Mountains was probably deposited within the neritic zone on smooth marine floors generally favorable for abundant shell life.

LOWER AND UPPER CRETACEOUS SERIES

ROCKS OF WASHITA AGE

Rocks of Washita age are exposed in several widely separated localities in the southeastern part of the report area. They form low hills near the Sierra Blanca peaks and the north end of the Quitman Mountains, several long belts of outcrop in Eagle Flat northeast of Devil Ridge, and the crests and east slopes of the southern part of the Quitman Mountains. In all these occurrences, the rock is mainly limestone. Its thickness could not be determined certainly but is probably between 1,020 and 1,400 feet. Rocks of Washita age are conformable with the underlying Kiamichi Formation and the overlying Upper Cretaceous rocks.

LITHOLOGY AND THICKNESS

Most of the rocks of Washita age in the southern part of the Quitman Mountains are light-gray limestone that weathers gray or bluish gray. The limestone is crystalline, granular or sugary, and in part contains small amounts of quartz sand. Some beds are made up almost entirely of large rudistids embedded in crystalline limestone. Most of the limestone is in 1- to 4-foot thick beds, but some massive layers are 10 to 12 feet thick. In places, the beds are separated by 6- to 8-inch-thick partings of gray shale. A persistent fossiliferous zone of poorly exposed thin-bedded limestone, shale, and platy calcareous sandstone lies 110 to 160 feet above the base of the group.

In the southeastern part of the report area and beyond, the rocks of Washita age are divisible into three units (Smith, 1940, sec. 5, p. 629): the upper, almost 200 feet thick, is limestone and sandy limestone; the middle, about 150 feet thick, is poorly exposed sandstone, calcareous sandstone, and some shale; the lower, about 680 feet thick, is limestone, marly limestone, and some shale. Contact with the underlying Kiamichi Formation is not exposed. Fossils are most abundant in marly limestone beds 480 to 580 feet below the top of the sequence (Smith, 1940, p. 616).

A shaly phase of the Washita is well exposed on the north side of Round Top. Black shale, greenish-brown shale, nodular limestone, and gray laminated calcareous sandstone are interbedded in layers no more than 4 inches thick. One deep gulch exposes an angular unconformity within these thin-bedded strata. Beds below the unconformity are bent into folds 2 to 3 feet across, many of which are overturned or even recumbent to the northeast, whereas beds above the break are tilted but not folded. This unconformity was not observed elsewhere and is probably a local feature caused by subaqueous gliding of sediments.

All the strata of Washita age near the intrusive stock at the north end of the Quitman Mountains have been variously metamorphosed. The limestone is recrystallized and altered in places to lime-silicate rocks containing conspicuous zones of garnet; the sandstone is altered to quartzite, and the shaly beds, to hornfels.

Just east of the report area north of Devil Ridge, a thickness of 1,020 feet of these beds is overlain by Upper Cretaceous rocks, but the base is not exposed (Smith, 1940, p. 616, 629). A thickness of about 675 feet occurs in the Quitman Mountains near the south border of the report area, but here the top of the group has been eroded, and numerous faults make accurate measurements difficult.

The Espy Formation of Huffington (1943, p. 1006, 1011), which includes the rocks of Washita age of this report, is 1,286 feet thick in hills east of the northern part of the Quitman Mountains, but its upper 266 feet is here assigned to our Upper Cretaceous map unit.

The Haymon Krupp Oil and Land Co. Briggs 1 well, at the northwest end of the Malone Mountains, evidently went through a complete section of rocks of Washita age and revealed a thickness of about 1,375 feet (fig. 52).

RELATION TO KIAMICHI FORMATION

The contact between the rocks of Washita age and the Kiamichi Formation is visible only in the southern part of the Quitman Mountains, where it is marked by a change from brown weathering calcareous sandstone below to gray crystalline limestone above, and is obviously conformable. Commonly, the rocks of Washita age crop out conspicuously above the more poorly exposed Kiamichi.

FOSSILS

Among the rocks of Washita age, the marly or shaly beds are abundantly fossiliferous and yield many well-preserved specimens that weather free. The massive limestone beds are fossiliferous in many places, but the fossils are fragmental and do not weather from the rocks. Some of the massive limestone beds in the southern part of the Quitman Mountains are made up of masses of horn-shaped rudistids as much as 1½ feet long.

Our megafossil collections were identified by R. W. Imlay and are chiefly from three localities: (1) in gray nodular limestone 110 to 160 feet above the base of the sequence on the east side of the southern part of the Quitman Mountains, about 11 miles south of the town of Sierra Blanca (USGS Mesozoic loc. 21073), (2) in gray shale, marl, and thin-bedded limestone between Sierra Blanca Peak and Little Blanca Mountain (USGS Mesozoic loc. 21074), and (3) in gray shale, marl, sandstone, and nodular limestone on the north side of Round Top (USGS Mesozoic loc. 21075). Additional fossils were collected earlier by Smith (1940, p. 616–617) from gray marl and marly limestone 480 feet below the top of the sequence north of Devil Ridge.

Foraminifers

The large arenaceous foraminifer *Haplostiche texana* (Conrad) is so abundant in places that its sandy tests give a brownish cast to limestone surfaces. Several of these beds, each about 4 feet thick, are interstratified with calcareous sandstone through a thickness of about 20 feet between Round Top and Little Round Top. Samples for examination of the smaller Foraminifera were not taken from the rocks.

Gastropods

Gastropods are common locally but are mostly preserved as molds, so that specific or even generic identifications are impossible. *Aporrhais?* sp. occurs in shale and marl beds between Sierra Blanca Peak and Little Blanca Mountain. Many gastropods occur in the gray marl and marly limestone about 480 feet below the top of the rocks of Washita age east of the report area and northeast of Devil Ridge (Smith, 1940, p. 616–617).

Brachiopods

Kingena sp. is present in all the collections but is especially abundant in the southern part of the Quitman Mountains in a stratigraphic interval of about 50 feet at 110 feet above the base of the unit. In places, its shells litter the slopes and afford a stratigraphic marker in an otherwise uniform sequence.

Pelecypods

Pelecypods are abundant throughout the rocks of Washita age. Beds along the arroyo between Sierra Blanca Peak and Little Blanca Mountain contain *Neithea texana* (Roemer), *Lima wacoensis* Roemer, *Ostrea* (*Lopha*) *quadriplicata* Shumard, *Volsella* sp., and *Pholadomya* sp. Gray shale, marl, sandstone, and nodular limestone on the north side of Round Top contain *Neithea texana* (Roemer), *Gryphaea corrugata* Say, and *Trigonia emoryi* Conrad. *Plicatula* sp. occurs in the *Kingena* zone in the southern part of the Quitman Mountains.

Cephalopods

Cephalopod fragments are common in some beds but are rarely well enough preserved to be identifiable. *Pervinquieria* cf. *P. trinodosa* (Böse) occurs in a zone 110 feet above the base of the unit in the southern part of the Quitman Mountains; *Cymatoceras* sp., at the arroyo between Sierra Blanca Peak and Little Blanca Mountain; and *Pervinquieria trinodosa* (Böse), *Pervinquieria* sp. aff. *P. trinodosa* (Böse), and *Pervinquieria* aff. *P. kiliani* (Lasswitz), on the north side of Round Top.

Echinoids

Many beautiful echinoid specimens are found but all belong to wide-ranging species. They are most common around the Sierra Blanca peaks and northeast of Devil Ridge. The type specimen of the large and ornate *Stereocidaris hudspethensis* Cooke (Cooke, 1955, p. 88–89) is from a small outcrop slightly more than 1 mile north of Round Top.

Echinoids collected from outcrops along the arroyo between Sierra Blanca Peak and Little Blanca Mountain and identified by Cooke (1946, 1955) include: *Dumblea symmetrica* Cragin, *Holectypus* (*Coenholectypus*) *transpecosensis* Cragin, *Enallaster* (*Washitaster*) *bravoensis* Böse, *Tetragramma streeruwitzi* (Cragin), *Phymosoma texanum* (Roemer), *P. mexicanum* Böse, *Orthopsis occidentalis* Cragin, *Globator parryi* (Hall), and *Holaster laevis* (Brongniart). Cooke (1946, p. 227–228) also lists *Hemiaster* (*Ma-*

craster) *elegans* Shumard from the southeast side of Sierra Blanca Peak.

AGE AND CORRELATION

We found it impracticable to divide the rocks of Washita age into formations. In the southern part of the Quitman Mountains, they constitute an almost homogeneous lithologic unit. In the area around the Sierra Blanca peaks, several rock units are distinguishable locally, but exposures are so discontinuous that a much more detailed stratigraphic and paleontologic study would be required to establish a definite sequence.

According to Imlay (written commun., 1950), the collections from 110 feet above the base of the sequence in the southern part of the Quitman Mountains, as well as those from between Sierra Blanca Peak and Little Blanca Mountain and from the north side of Round Top, "are clearly of Washita age and probably belong low in the group, as the forms of *Pervinquieria* are similar to those in the Duck Creek and Ft. Worth limestones."

All the echinoids are characteristic of the Washita except *Enallaster texanus* (Roemer), which ranges from the Trinity into the Washita Group (Cooke, 1946, p. 196–197).

The upper rocks of Washita age in the Sierra Blanca area may be equivalent to the Buda Limestone and underlying Grayson Formation recognized in the Eagle Mountains to the southeast (Gillerman, 1953, p. 10–11, 27–31), but positive equivalence has not been established.

CONDITIONS OF DEPOSITION

The beds of Washita age were deposited in a neritic environment at a time when the shoreline was much farther north than at any earlier stage of the Cretaceous. They are known at Sierra Prieta and as far north as the Cornudas Mountains of northern Hudspeth County (Adkins, 1932, p. 354, 362).

In the southernmost part of the Sierra Blanca area, limestone was the principal deposit, although some very fine grained clastic sediment was introduced occasionally, forming the shaly and marly beds. Northward, toward the shore, the proportion of fine clastic material increases. Marine life was abundant and varied. Rudistids formed reefs, and many other shellfish contributed their skeletons to the limy sediment.

UPPER CRETACEOUS SERIES (UNDIFFERENTIATED)

In the report area, rocks of the Upper Cretaceous Series above rocks of Washita age are preserved only between the Quitman Mountains and Sierra Blanca Peak where they crop out near the Etholen Knobs and about 1¼ miles southwest of East Etholen Knob. Here the rocks are chiefly sandstone and siltstone, of which as much as 675 feet is preserved; the top is missing. The series is exposed more extensively and in greater thickness in the Eagle Mountain area just southeast of the report area (Baker, 1927, p. 30; Smith, 1940, p. 617–618, and 1941, p. 73–74; Gillerman, 1953, p. 32–33).

The beds in the Sierra Blanca area were included by Huffington (1943, p. 1004–1007) in the upper part of his Espy Formation, but as this unit can be divided into its Washita and Upper Cretaceous components, this name is not used in this report.

These undifferentiated rocks of Late Cretaceous age consist of sandstone, siltstone, and shaly siltstone. The sandstone is gray or pale red and weathers brown or greenish brown. It is mostly evenly laminated, but some layers are crossbedded and rippled on a small scale. The sandstone is fine to very fine grained, and much of it is arkosic. Some lenticular beds contain limestone pebbles, chiefly half an inch but as much as 2 inches in diameter. Calcareous concretions, many with septarian structure, occur in parts of the sandstone. The siltstone is of the same color as the sand-

SECTION 16.—*Section of Upper Cretaceous rocks*

[East side of West Etholen Knob; traverse 16 shown on pl. 3. Fossil identifications by L. W. Stephenson]

	Thickness (feet)
Top of section is at Devil Ridge thrust fault; Etholen conglomerate in upper plate.	
Upper Cretaceous:	
5. Sandstone, pale-red, fine-grained, arkosic, massive, fractured; bedding absent or indistinct	125
4. Sandstone and siltstone, interbedded; yellowish-brown fine-grained arkosic sandstone in 1- to 6-in. beds	15
3. Siltstone, greenish-brown to gray; weathers brown with green cast; laminated and platy in part, plates being ⅛ to ¼ in. thick; some shaly siltstone in 3-in. to 3-ft beds; interbedded very fine grained 3-in. to 2-ft sandstone beds	227
2. Sandstone, gray, brown-weathering, fine-grained; numerous 1- to 2-ft-thick lenses of fossiliferous sandstone, some of which are almost coquinites; contains *Ostrea* cf. *O. soleniscus* Meek, *Ostrea* sp., *Cardium* sp., and *Glauconia*? (USGS Mesozoic loc. 25765); 16 ft below top is a sandstone bed 8 in. thick that contains limestone pebbles ¼ to 2 in. in diameter	108
1. Sandstone, unexposed to poorly exposed, gray (weathers brown with green cast), very fine grained, evenly laminated; in 1- to 2-ft beds; breaks with rough conchoidal fracture; some laminated gray siltstone, weathers brown with green cast; contains scattered very fine sand grains; base not exposed	200
Total exposed thickness	675

stone and forms evenly laminated beds 1 inch to 3 feet thick.

The most complete section of the Upper Cretaceous rocks is on the flanks of West Etholen Knob and in the adjoining flat (section 16), but even here exposures are poor and minor faults so numerous that more energy is required to find the sequence than to measure it.

Rocks of the Upper Cretaceous Series are apparently conformable on the rocks of Washita age, but the contact is exposed in such small areas that the possibility of minor erosional or angular discordance is not disproved. Northeast of West Etholen Knob and at the north end of the Quitman Mountains, the lithologic change from limestone beds of Washita age to sandstone and siltstone beds of the Upper Cretaceous Series is distinct, although the contact itself is mostly covered with rubble. Where the rocks are metamorphosed, the change is from recrystallized limestone to quartzitic sandstone or hornfels.

The lower part of the Upper Cretaceous Series in west Texas has been referred to the Eagle Ford Formation by many authors (for example, Adkins, 1932, p. 436–438), but the sections exposed in our area and the fossils collected from them are too meager to permit subdivision or more than broad correlations; therefore, these rocks are undivided.

Many of the beds in the Upper Cretaceous in the Sierra Blanca area are very fossiliferous, and some consist largely of broken shell fragments; however, most of the fossils are poorly preserved. L. W. Stephenson identified the following from the east side of West Etholen Knob (USGS Mesozoic loc. 25765): *Ostrea* cf. *O. soleniscus* Meek, *Ostrea* sp. (small), *Exogyra* sp. (similar to a small undescribed species from the base of the Woodbine Formation, Hill County, Tex.), *Cardium* sp., and *Glauconia*?.

These strata are placed in the Upper Cretaceous partly on fossil evidence and partly because of their similarity to proved beds of Late Cretaceous age farther eastward. *Ostrea soleniscus* Meek is common in the Woodbine Formation of central and northeast Texas. The known range of *Ostrea soleniscus* Meek permits correlation with the Eagle Ford Formation, although it also occurs in formations below and above the Eagle Ford (Cobban and Reeside, 1952, chart).

The Upper Cretaceous rocks probably were deposited on the floor of a body of shallow water as fine clastic material which was transported by gentle currents. Because oysters grew abundantly and virtually to the exclusion of other kinds of benthonic life, the environment of a brackish bay rather than the edge of an open sea is suggested.

TERTIARY AND QUATERNARY SYSTEMS

In the report area the oldest rocks of probable Tertiary age are the Square Peak Volcanics in the northern part of the Quitman Mountains, where there are also intrusive rocks that can be only slightly younger than the volcanics. Intrusive rocks in other parts of the area are presumed to be about the same age as those in the northern part of the Quitman Mountains. The volcanic rocks rest with angular unconformity on the Cretaceous strata, which were folded and faulted during the major orogeny that affected the area and were then uplifted and extensively eroded before the lavas erupted. Interpretation of the history following deposition of the Cretaceous beds is handicapped by a lack of any direct dates on these igneous rocks. The only beds of Tertiary and Quaternary ages that are dated on the basis of contained fossils are basin deposits which are exposed mainly in the Hueco Bolson and are unconformable on the igneous rocks. Although mapped as one unit, these basin deposits consist of two units, the older of which is probably Pliocene and the younger probably early Pleistocene. Five formations of gravels on erosional surfaces are younger than the basin deposits, and two terrace deposits along the Rio Grande are still younger. Alluvium, colluvium, and windblown sand are widespread in the area and make up the youngest deposits.

Discussion of the rocks of the Tertiary and Quaternary Systems is arranged generally according to age sequence of the units in so far as the sequence is known. Because the youngest units are in part equivalent, however, their presentation by age is not followed in a strict sense.

IGNEOUS ROCKS OF TERTIARY AGE

Igneous rocks have their greatest areal extent and their greatest volume in the central part of the Sierra Blanca area, in the northern part of the Quitman Mountains, and in the Sierra Blanca peaks, but smaller bodies occur in other parts of the area. A thick body of chiefly rhyolitic and trachytic lava (the Square Peak Volcanics) occupies a circular area in the northern part of the Quitman Mountains. Intrusive igneous rocks form a stock, laccoliths, and miscellaneous bodies, which include attendant sills and dikes. The large intrusive bodies of the northern part of the Quitman Mountains are discordant, but those of the Sierra Blanca peaks are largely concordant.

We undertook no comprehensive petrographic study of the igneous rocks, although we made field observations on their gross structures and shapes, their age relations with respect to each other and to adjacent sedimentary rocks, and lithologic variations within the larger bodies.

IGNEOUS ROCKS OF THE NORTHERN PART OF THE QUITMAN MOUNTAINS

Extrusive and intrusive igneous rocks cover most of the northern part of the Quitman Mountains. This area was studied by Huffington (1943, p. 1027–1043; petrographic description, p. 1027–1038) from whose report the following discussion is in part summarized.

SQUARE PEAK VOLCANICS

The Square Peak Volcanics, which were named Square Peak Volcanic Series by Huffington (1943, p. 1027), form some of the highest and most rugged peaks of the northern part of the Quitman Mountains. They have a total thickness of about 3,500 feet and consist of about 80 percent rhyolite and trachyte flows, 5 to 10 percent latite and quartz latite flows, 1 to 5 percent andesite and basalt flows (only one basalt flow was noted), 1 to 5 percent tuff (welded and crystal of rhyolitic to trachytic and quartz latitic composition), and 5 to 10 percent breccia and flow conglomerate. The lavas are generally fine grained and are equigranular to porphyritic; some are massive, others are vesicular, and some have conspicuous flow banding. In places, flow conglomerate, volcanic breccia, and tuff are interspersed between flows. Most of the individual volcanic rock units cannot be traced far, although one flow conglomerate was traced about 8,000 feet along the strike. Single flows or units of flow conglomerate are a few feet to 200 feet thick. The flow conglomerates consist of fragments of older lavas and sedimentary rocks in an igneous matrix. The sedimentary rock fragments appear to have been derived chiefly from gravel or rubble over which the lavas flowed.

Although the volcanic rocks are not perfectly stratified according to differences in composition, a general order of succession is apparent. The earlier volcanic rocks are mostly rhyolitic. Next above is a sequence of interbedded trachyte and rhyolite succeeded by a few flows of latite. The youngest lavas are chiefly trachytes that approach rhyolite in composition and are more vesicular than the earlier flows. Flows containing a high percentage of lava fragments are most numerous in the lower half of the volcanic series.

This succession of rocks in the Square Peak Volcanics broadly resembles the sequence in the Eagle Mountain area, about 20 miles to the southeast, where Gillerman (1953, p. 35–37) identified two rhyolitic series separated in time by trachyte porphyry.

The vents or fissures from which the Square Peak Volcanics issued have not been found, although a possible minor vent may be represented by a small breccia pipe that cuts the Bluff Mesa Limestone on the west wall of Black Canyon; this pipe is shown as part of the Square Peak Volcanics on the geologic map, plate 1. Other feeders may have been obliterated by the younger intrusive rocks.

INTRUSIVE ROCKS

The Quitman pluton (Huffington, 1943, p. 1034), the main pluton in the northern Quitman Mountains, forms a ring-shaped outcrop around the Square Peak Volcanics. The ring is continuous at the surface except on the east side where it is covered by alluvium in places, but isolated hills of intrusive rock suggest that the pluton is almost continuous beneath the Quaternary deposits. The oldest rocks in the pluton are diorite and quartz diorite, which remain only as scattered small bodies and as inclusions in the younger rocks. Quartz monzonite and lesser amounts of granodiorite form most of the pluton, but monzonite, granite, and syenite each account for about 10 percent of the volume. Most of the rocks are gray to pink, but some are green or yellowish brown. All are porphyritic to finely or coarsely granitic. Aplite and granite porphyry occur locally along the borders of the pluton, and a hybrid rock is common along contacts with the lavas.

Several dikes cut the northern part of the pluton, and small outlying dikes and sills intrude the Bluff Mesa Limestone on Bug Hill. They consist of aplite, granite porphyry, rhyolite porphyry, and quartz latite porphyry.

STRUCTURE AND ORIGIN

In plan, the igneous rocks in the northern part of the Quitman Mountains form an oval mass which is elongate north to south. The Square Peak Volcanics occur in the center of the mass. Structurally, these volcanic rocks occur in a northward-trending asymmetric syncline, whose west limb dips about 40° on the average and whose east limb dips about 20°. Some layers are vertical to overturned near the margins of the outcrops of the volcanic rocks, and several small folds are superimposed on the main syncline. This syncline appears to be unrelated to the structure in the older sedimentary rocks and thus related only to the structural development of the igneous rocks.

The intrusive rocks making up the plutonic part of the mass of igneous rocks form an almost continuous ovate body surrounding the volcanic rocks. This pluton is younger than the Square Peak Volcanics and cuts across both the lavas and the sedimentary rocks along *steep contacts*. A water well drilled about 1½ miles southeast of Hilltop Cafe, within 150 feet of the west side of the pluton, penetrated sedimentary rock for 610 feet without entering the igneous rock; consequently, this part of the contact at least must be nearly vertical or perhaps even inclined toward the pluton.

The rocks within the ring formed by the pluton have evidently subsided to form the syncline in the Square Peak Volcanics. As pointed out by Huffington (1943, p. 1042), the central part of the volcanic rocks appears to have subsided about 3,000 feet, but the sedimentary beds adjacent to the inner side of the ring of the pluton seem to have subsided very little. On the west side of the mountains the sedimentary beds on the inner side of the ring may have subsided as much as 300 feet.

The Quitman pluton is interpreted as a ring dike having an accessory stock at the north end (Huffington, 1943, p. 1040–1043). Our observations confirm the general concept, although we believe that the straight part of the dike at the south end was largely controlled by an older fracture developed during the general deformation of the region and along which there was later movement. The areal relation between the central volcanic rocks and the ring dike and the subsidence of the rocks within the ring suggest that this entire structure might also be interpreted as an ancient small caldera (Williams, 1941, p. 242 and 246) that has been so eroded that the topographic form of the caldera no longer remains. Basining of the Square Peak Volcanics inside the ring of the pluton may have been caused by recession of magma from a chamber below the area during pulsatory intrusive action.

INTRUSIVE ROCKS OF THE SOUTHERN PART OF THE QUITMAN MOUNTAINS

Dikes and some sills of rhyolite porphyry cut formations of Early Cretaceous age in the southern part of the Quitman Mountains. Most of the dikes trend east-northeastward and were probably intruded along shear fractures formed during the folding and thrusting of the area; the widest is almost 300 feet across, but most are less than 50 feet.

The fresh rock of both dikes and sills is almost white (*N*9) to moderate yellowish brown (10*YR* 5/4) and weathers brown. The color determinations were made on hand specimens, and colors with numerical designations match those of the "Rock-Color Chart" distributed by the National Research Council (Goddard and others, 1948).

Quartz, plagioclase, and biotite phenocrysts occur in a fine-grained groundmass that consists of alkalic feldspar, quartz, and smaller amounts of biotite. The texture is hypautomorphic to xenomorphic granular. Green pitchstone forms part of a rhyolite sill in the Kiamichi Formation near the east side of the range.

INTRUSIVE ROCKS OF THE FINLAY MOUNTAINS

GENERAL FEATURES

Dikes and sills of andesite and latite porphyries are unusually abundant in the Finlay Mountains, the dikes mainly in the west half of the range and the sills mainly in the south half and the southeast quarter. Only the more prominent dikes and sills are shown on the geologic map (pl. 1).

Most of the dikes are 2 to 10 feet wide, but a few are as much as 100 feet. They dip 70° to vertical and fill joints and faults in strata of Permian and Cretaceous age. In the western part of the Finlay Mountains, the dikes radiate from the center of a broad structural dome. A smaller dome to the east shows no such pattern but is cut by the largest dike in the area.

The sills are a few feet to 75 feet thick. Most of them lie between beds of sandstone and limestone in the upper part of the Cox Sandstone and the lower part of the Finlay Limestone and thus are mainly in beds higher stratigraphically than those in which most of the dikes occur.

The dikes and sills belong to the same episode of intrusion and are similar in composition. In parts of the western Finlay Mountains, dikes join the floors of sills without change of lithology or without crosscutting. Many dikelets issue from the upper parts of sills and fill cracks in overlying strata. In most places, however, the paths by which magma rose to enter the sills are not visible. The two domes and the pattern of radiating dikes in the larger one suggest that the sources of the magma in the dikes and sills may have been from intrusive bodies beneath the domes. Such intrusive bodies probably caused the doming, as discussed further in the section on structure.

PETROGRAPHY

The dikes and sills consist of latite porphyry, andesite porphyry, and hornblende andesite porphyry. All are holocrystalline and have phenocrysts of feldspar and amphibole set in a microcrystalline groundmass. Some of the thicker sills are differentiated and consist of both andesite and latite or of andesite and hornblende andesite.

Andesite porphyry is most common. Fresh surfaces of the rock are light olive gray (5*Y* 6/1) to pale yellowish brown (10*YR* 6/2). The phenocrysts of andesine or oligoclase, hornblende, and augite are mostly euhedral, and are from 0.5 to 3.5 cm long. Feldspar laths in the groundmass are subparallel in some sections and randomly oriented in others.

Hornblende andesite porphyry forms many of the dikes and sills in the western part of the mountains. This rock is light to dark gray, commonly with an olive to greenish cast (5*Y* 6/1 to 5*GY* 4/1). Crystals of hornblende 0.3 to 1.0 cm long ordinarily make up 10 to 25 percent of the rock. These, along with euhedral crystals of plagioclase (andesine to labradorite) and scattered books of biotite, are set in a matrix of feldspar laths.

Latite porphyry forms a few of the thicker sills in the southeastern part of the mountains. This rock is generally lighter colored than the others and ranges from light olive gray (5*Y* 6/1) to grayish orange (10 *YR* 7/4) and pale red (10*R* 6/2). Orthoclase and sanidine crystals 2 mm to 2 cm long form the more conspicuous phenocrysts. These and smaller crystals of sodic plagioclase and ferromagnesian minerals are embedded in a generally trachytic groundmass of feldspar laths.

All three varieties of rock are generally somewhat altered. Most feldspar grains contain some secondary sericite and calcite in and around them, and the amphibole is locally altered to chlorite and carbonate minerals.

RELATIONS TO FAULTS

The intrusive bodies are younger than the conspicuous high-angle fault that cuts westward along the southern part of the mountains. At least five sills end against one side or the other of this fracture, without evidence of faulted extensions on the opposite side. In several places dikes that show no shearing are frozen against the fault plane or occupy parallel breaks nearby.

The joints and minor faults radiating from the west dome are evidently tension cracks formed during the arching of the sedimentary rocks. Because the dikes that occupy many of these fractures are unsheared and firmly frozen to the wallrock on either side, the fractures must be older than the dikes. The same is true of a thick dike that follows the fault along the west side of the east dome. If the twin domes were uplifted by laccoliths or stocks, the dikes may have been emplaced very soon after development of the radial and peripheral fractures.

The intrusive bodies are older than minor vertical faults of northerly trend in the southeastern part of the mountains. These faults are not followed by dikes, and they displace several sills by as much as a few tens of feet.

INTRUSIVE ROCKS OF THE FLAT MESA-TEXAN MOUNTAIN AREA

GENERAL FEATURES

In the Flat Mesa-Texan Mountain area, latite porphyry forms sills and mainly vertical dikes in the Cox Sandstone. One prominent sill on Texan Mountain is along the contact between the Cox Sandstone and the Finlay Limestone. Several of the sills are almost 250 feet thick. Contacts between the sills and sedimentary rocks are slightly irregular in detail.

PETROGRAPHY

The latite porhyry is yellowish gray (5*Y* 7/2) to light olive gray (5*Y* 6/1), except where iron oxide has imparted an orange cast. Many of the sills contain prominent sanidine phenocrysts as much as 2 cm long which weather from some outcrops in a multitude of perfect crystals. (See Lonsdale and Adkins, 1927.)

The groundmass is aphanitic and forms about 60 percent of the rock. As seen in thin section, feldspars compose about 95 percent of the identifiable phenocrysts in the groundmass. Some hornblende occurs in needles a few millimeters long, and a little quartz is found in rounded and corroded grains scarcely more than a millimeter in diameter. The ratio of plagioclase, chiefly oligoclase, to potassic feldspar is 2:1 to 3:1. The plagioclase laths are less than 3 mm long. Accessory sphene, apatite, hornblende, and probably magnetite form about 2 percent of the rock. Secondary calcite has partially replaced the other minerals.

INTRUSIVE ROCKS OF THE SIERRA BLANCA PEAKS

LACCOLITHS

Structure

Five rhyolitic laccoliths form Sierra Blanca, Round Top, Little Round Top, Little Blanca Mountain, and Triple Hill.

The Sierra Blanca, Round Top, Little Round Top, and Little Blanca Mountain laccoliths intruded strata of Washita age. The Triple Hill laccolith intruded limestone beds of the Campagrande Formation, at least 1,600 feet stratigraphically below the beds invaded by the other laccoliths.

At several localities sedimentary strata overlie these intrusive bodies concordantly. On the south side of Sierra Blanca, beds of Washita age rest against the igneous rock and dip southwest at an angle of about 55° (fig. 41). The contact is parallel to the bedding, and the sedimentary rocks directly above it are altered to quartzite and hornfels. At Triple Hill, strata of

FIGURE 41.—Rocks of Washita age (Kw) on rhyolite porphyry (Tr) of the Sierra Blanca laccolith. The beds dip steeply to the southwest (left), and the contact is even and parallel to the bedding. As the photograph was taken at an angle and from above, only an apparent dip is seen.

the Campagrande Formation dip west and south off the flanks of the intrusive body. The contact between the igneous and sedimentary rocks is regular on a broad scale but irregular in detail. These and similar exposures indicate that the sedimentary strata were domed over the intrusive bodies, and dips of the beds adjacent to the bodies suggest, moreover, that the present slopes of the mountains approximate the original contours of the intrusives (fig. 42).

The floor of the Round Top laccolith is partly exposed on the north side of Round Top, where shale and marl of Washita age dip 10° to 15° SW. beneath the igneous rock (fig. 43). The contact is concordant and, as seen near the outer edge, is slightly concave upward, suggesting that the shape of the intrusive may be asymmetrically biconvex in vertical section.

The probable floor of the Triple Hill laccolith was penetrated in a water well drilled on the north side. According to the driller's log, beneath 4 feet of gravel was 1,000 feet of "granite" rock on top of "red rock" that was easy to drill and from which water was obtained. This red rock, probably siltstone and sandstone in the lower part of the Campagrande Formation, was penetrated for about 100 feet to the bottom of the hole.

The floors of the laccoliths in the Sierra Blanca peaks group apparently slope southwestward in the same general direction as the regional dip of the underlying sedimentary rocks (pl. 8) but at a lesser angle. The scattered exposures of the basal contacts do not disclose whether this slight discordance is an incidental or an essential feature.

Petrography

All the laccoliths are fine-textured rhyolite, which is locally porphyritic.

The Sierra Blanca laccolith consists of uniform leucocratic rhyolite porphyry, pinkish gray (5*YR* 8/1) or very pale orange (10*YR* 8/2). Conspicuous round quartz phenocrysts 0.04 to 2.0 mm across are set in an aphanitic groundmass along with some bio-

FIGURE 42.—Laccoliths of Round Top (left) and Little Round Top (right). View is northwestward from northwest side of Sierra Blanca peak. Rocks of Washita age crop out in the saddle between the mountains. The fine-grained rhyolite forming the laccoliths is much more resistant to erosion than the sedimentary rocks, and the shape of Round Top particularly may approximate the original shape of the laccolith.

tite phenocrysts. The texture of the groundmass is hypautomorphic to xenomorphic granular. Quartz makes up about 60 percent of the rock, feldspar (largely albite) about 35 percent, and biotite about 5 percent.

The rhyolite in Little Blanca Mountain is aphanitic and not porphyritic. It is generally of the same color as the Sierra Blanca rock but in places is nearly pale red (10*R* 6/2). Some of the weathered surfaces are slightly banded so that the rock looks like a quartzite. It consists of about 65 percent quartz, 30 percent feldspar (chiefly albite), and 5 percent biotite and contains scattered opaque crystals that are probably magnetite. The largest phenocrysts observed in thin section are 0.25 mm for quartz and 1 mm for feldspar. Most of the rock in Round Top and Little Round Top resembles that in Little Blanca Mountain.

The rhyolite porphyry of the Triple Hill laccolith is chiefly pale red (5*R* 6/2) or yellowish gray (5*Y* 7/2). Conspicuous albite phenocrysts range from 0.3 to 1.2 mm across. The rock consists of about 65 percent quartz, 25 percent feldspar (chiefly albite), 5 percent biotite, and about 5 percent of an opaque mineral that probably is magnetite. In places, secondary calcite replaces the other minerals, especially the feldspar.

SILLS AND DIKES

Several sills and dikes intrude the sedimentary rocks on the flanks of the laccoliths. Some are probably apophyses of the laccoliths, such as the sills of rhyolite porphyry near Sierra Blanca peak and one sill near the roof of the Triple Hill body. Others, however, are of different composition; they consist of andesite, hornblende andesite porphyry, and latite porphyry similar to rocks in the Finlay Mountains. None of the visible dikes appear to have been conduits for the laccoliths.

SILLS ON THE DIABLO PLATEAU

Sills occur on the Diablo Plateau at Granite Mountain, which is at the north edge of the mapped area, and on a low hill about 4 miles northeast of the Gunsight Hills.

The Granite Mountain sill is a body of sodalite syenite almost 200 feet thick. This intrusive may be sufficiently convex to be classed a laccolith, but exposures are not complete enough for determination of its principal dimensions. The sill lies in the Cox Sandstone, between siltstone and shaly siltstone below and limestone above. It dips gently southwestward, parallel to the enclosing strata. The sodalite syenite is chiefly light olive gray (5*Y* 6/1), is fine-grained, and has a hypautomorphic-granular texture. It consists of about 15 percent anhedral sodalite

FIGURE 43.—Rhyolite (Tr) of the Round Top laccolith on shale and marl of Washita age (Kw). Note that beds just below the contact can be traced completely across the exposure and that the igneous rock does not cut across the sedimentary beds.

grains in spaces between orthoclase crystals and contains accessory biotite and hornblende.

A sill on a low hill about 4 miles northeast of the Gunsight Hills is of andesite and is about 20 feet thick. On the east side of the hill, a dike about 75 feet wide joins the sill from below. Beds of the Finlay Limestone above the sill are tilted slightly northward, and a sandstone beds in the Finlay is altered to quartzite. The andesite consists of about 60 percent plagioclase (chiefly andesine), 15 percent hornblende and augite, 15 percent biotite, and 10 percent an opaque mineral that probably is magnetite. Apatite is an accessory mineral. The texture is ophitic; plagioclase laths are as much as 1.25 mm long. Some of the hornblende is altered to chlorite. Secondary calcite occurs throughout.

AGE OF THE IGNEOUS ROCKS

No exact age can be placed on the igneous rocks in the report area, although limiting ages are established. These rocks, both extrusive and intrusive, are younger than the Laramide orogeny of probable late Late Cretaceous or early Tertiary age and older than the older basin deposits of probable Pliocene age. The Square Peak Volcanics rest with angular unconformity on the Cretaceous formations, a fact which indicates that the country had been uplifted and eroded extensively after deformation and before the lavas flowed over the surface. Several dikes were intruded along fractures developed during the orogeny and thus, too, are younger than the deformation, although not necessarily much so. As fragments of the igneous rocks are incorporated in the older basin deposits, the igneous rocks obviously are older. After the main igneous activity, the region was uplifted and extensively eroded, and the present outline of the ranges and basins was principally established before deposition of the older basin fill.

In the northern part of the Quitman Mountains, the ring dike pluton is younger than the Square Peak Volcanics which it intrudes but is probably not much younger because the plutonic rocks are comagmatic with the central volcanics (Huffington, 1943,

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p. 1036; Billings, 1943, p. 134). Age relations between the Quitman pluton and the other intrusive rocks in the area remain unknown, but all intrusives are presumed to be about the same age.

The key unit in dating the igneous rocks is the Square Peak Volcanics. Although no fossils have been found in these rocks, some fossils have been collected by others from volcanic sequences elsewhere in Trans-Pecos Texas. Ages established for various units range from Eocene to Pliocene but, without more definite correlation than is now possible, afford no help to more exact dating of the Square Peak Volcanics.

Included fossils are plants from rhyolitic basal tuff in the Barrilla Mountains, dated as Eocene by E. W. Berry (1919, p. 3–4); the tooth of a rhinoceros (Hyracodon) from volcanic rock in the northeastern part of the Davis Mountains, dated as Oligocene by R. A. Stirton (Plummer, 1932, p. 805; Baker, 1934, p. 151); and land tortoises from rhyolitic tuffs in the Eagle Mountain area, dated as late Tertiary (Plummer, 1932, p. 804). Gillerman (1953, p. 34 and 51) concluded that the volcanic activity in the Eagle Mountains began in early Tertiary time and possibly continued into Pliocene time.

Along the southern front of the Davis Mountains, the Buck Hill Volcanic Series of Goldich and Seward (1948) was tentatively dated as Eocene and Oligocene by Goldich and Elms (1949, p. 1138, 1143–1145), largely on the basis of gastropods collected from fresh-water limestone in the unit; they suggested that these rocks are correlative in part with the Square Peak Volcanics. Others (Moon, 1953, p. 184; Erickson, 1953, p. 1358; Graves, 1954, p. 32) gave a similar age range to the Buck Hill Volcanic Series, although Erickson suggested that some of the unit might be Miocene. McAnulty (1955, p. 558) believed the youngest part of this series to be Pliocene.

On the basis of rather meager fossil evidence and also very tentative correlation over a long distance, the Square Peak Volcanics are early Tertiary, possibly as old as Eocene or Oligocene, and most of the intrusive rocks are only slightly younger.

SEDIMENTARY ROCKS OF TERTIARY AND QUATERNARY AGES

The Cenozoic sedimentary sequence consists of a variety of lacustrine, alluvial, colluvial, and eolian deposits ranging in age from probable late Tertiary to Recent. The Tertiary deposits fill the Hueco Bolson, where they are largely covered by gravel of Pleistocene age and younger sediments. The Recent deposits include alluvium along the courses of streams and probably much of the colluvium and windblown sand.

OLDER BASIN DEPOSITS

Exposures along arroyos in the Hueco Bolson disclose sequences of sedimentary rocks of two different ages which are not differentiated on the geologic map (pl. 1). Equivalent deposits are probably buried beneath the floor of Quitman Canyon east of the Quitman Mountains and of Eagle Flat but are not exposed east of the Hueco Bolson except in a small area just east of Quitman Gap.

The older basin deposits, locally deformed and broken by faults, consist of three facies: (1) conglomerate near the mountains, (2) gypsiferous clay near the center of the basin, and (3) intervening deposits of sand, silt, and clay. The three facies intergrade and intertongue (fig. 44).

The conglomerate facies was laid down as alluvial fans derived from the mountains and hills that border the Hueco Bolson or project above it. The conglomerate is thus of the class termed "fanglomerate."

As the fanglomerate was locally derived, its fragments vary according to the lithology of adjacent mountains and hills (fig. 45). Along the Finlay and Malone Mountains and the southern part of the Quitman Mountains, the fragments are chiefly limestone, sandstone and quartzite. Near the northern part of the Quitman Mountains, they are chiefly quartz monzonite and lava. Because the monzonite disintegrates readily to arkosic sand, its cobbles and boulders are not ordinarily transported far from the mountains.

The fragments in the fanglomerate are mostly angular, although some of their sharper edges are rounded. Wherever they are fairly well rounded, as at a few places along the margin of the southern part of the Quitman Mountains, they must have been derived from streams heading far back in the mountains. In most places the largest fragments are boulders 2½ to 3 feet in diameter, although at the mountain edge there are a few much larger and more angular blocks that were probably moved to the fans mainly by gravity.

Bedding and degree of sorting differ according to the texture of the materials in the fanglomerate. Fairly well sorted sand forms lentils several inches thick, and many pebbly beds with sandy matrices are distinctly stratified. Most accumulations of cobbles and boulders are obscurely bedded to massive and are very poorly sorted. A few of the finer deposits are crossbedded.

Degree of induration differs with the abundance of limestone fragments in the deposits, as the cementing

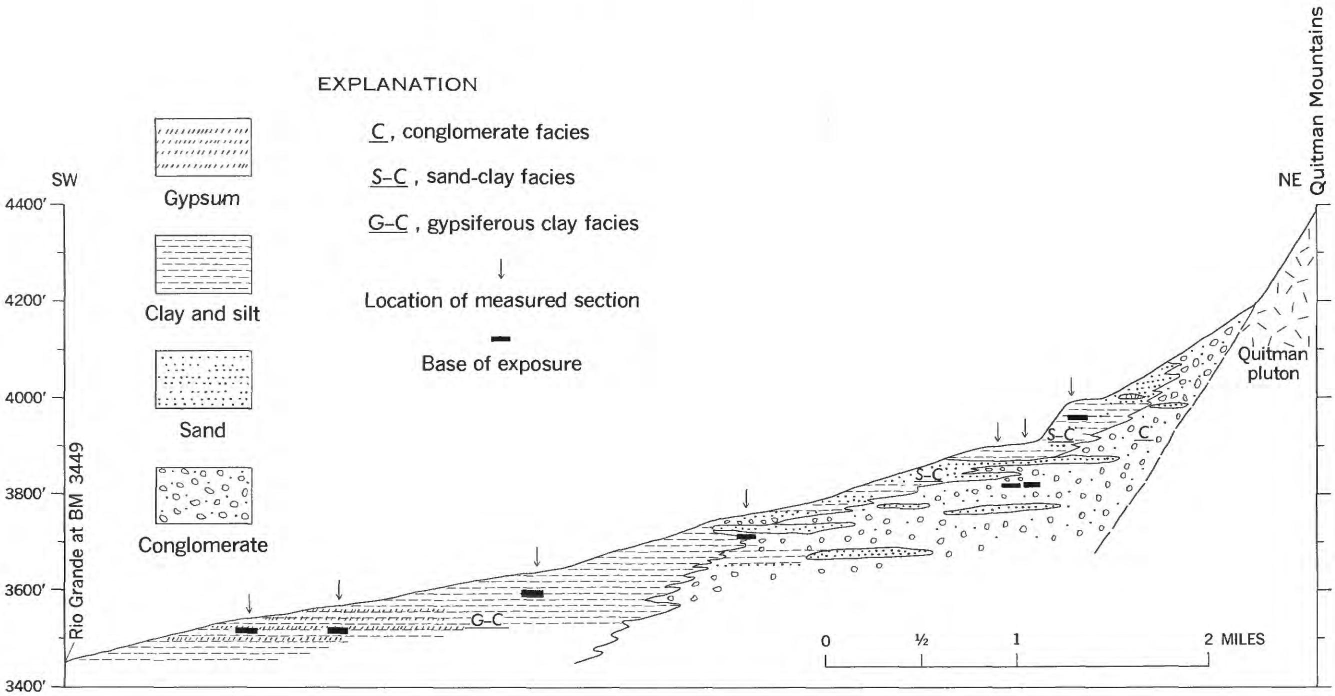

FIGURE 44.—Diagrammatic section showing relations between sedimentary facies in the older basin deposits in southern part of Hueco Bolson, from the Rio Grande at BM 3449 northeast to the Quitman Mountains. Section is based primarily on seven measured sections; base of exposure is indicated at each locality. Surface gravels are omitted.

FIGURE 45.—Older basin deposits, conglomeratic facies, exposed in the bank of an arroyo on the west flank of southern Quitman Mountains, along road from Sierra Blanca to Cox School.

material is calcium carbonate derived from partial solution of the limestone. Those deposits that contain abundant limestone clasts, for example, are much better cemented than those containing many fragments of monzonite. Conspicuous bands of caliche do not occur in the conglomerate facies.

The sand-clay facies is peripheral to the conglomerate faces. It consists chiefly of interbedded lenticular layers of sandstone, siltstone, and claystone and lentils of gravel. The amount of clay and silt increases away from the mountains, as the amount of sand diminishes.

The sand consists largely of fine quartz particles, partly in well-sorted beds but mostly in beds containing also clay or pebble-sized fragments. In the areas where drainage was from the northern part of the Quitman Mountains, much of the sandstone is arkosic. The sandstone is in units that range from fine laminations to accumulations as much as 20 feet thick. Some units are evenly stratified, others are crossbedded. Most of the sandstone is friable, but some is firmly cemented by calcium carbonate, the layers of different induration being interbedded in places.

The claystone is reddish brown to greenish gray and partly silty or sandy; it mostly forms massive layers, although some is evenly bedded and finely laminated.

The following stratigraphic section is representative of the sand-clay facies.

Section of sand-clay facies of older basin deposits

[West side of Arroyo Balluco, 6 miles northeast of Esperanza]

	Thickness (feet)
Madden Gravel (table 11):	
13. Caliche; probably formed from limestone gravel	3.0
Disconformity.	
Younger basin deposits:	
12. Sand, medium- to coarse-textured, cross-laminated; contains lentils of limestone gravel	11.0
Disconformity.	
Older basin deposits (sand-clay facies):	
11. Sand, laminated; contains fragments and lentils of reddish-brown clay	19.0
10. Clay, reddish-brown and green	8.0
9. Sand, gray	1.0
8. Clay, reddish-brown	1.0
7. Silt, gray	1.5
6. Clay, reddish-brown, sandy at base	12.0
5. Sand, fine-grained, laminated; small-scale cross-bedding	7.5
4. Clay, silty, massive; reddish brown at base, gray in upper part	11.0
3. Clay, silty, laminated	5.5
2. Sand, pink, laminated; some layers contain carbonate cement	6.5

Section of sand-clay facies of older basin deposits—Continued

	Thickness (feet)
Older basin deposits (sand-clay facies)—Continued	
1. Clay, reddish-brown; base not exposed	11.0
Total measured thickness of older basin deposits	84.0

The gypsiferous clay facies is farthest from the mountains, and its exposures are limited to a narrow strip along the Rio Grande. The best exposures are along arroyos about 2 miles southeast of Fort Quitman (fig. 46). The facies consists of interbedded clay, silt, gypsum, and gypsiferous clay and subordinate amounts of fine-grained sandstone. Calcareous claystone is the principal constituent. It is reddish brown, greenish gray, or almost white and in beds that are finely and evenly laminated to massive. Selenite crystals are scattered through the gypsiferous clays and in places are concentrated to form whole beds. Layers of coarsely to finely granular and sugary gypsum are in places as much as 1.5 feeet thick, and though lenticular, some of those southeast of Fort Quitman probably persist over areas of at least a square mile.

The following measured stratigraphic section is representative of the gypsiferous clay facies.

Section of gypsiferous clay facies of older basin deposits

[Arroyo about 2 miles southeast of Fort Quitman]

	Thickness (feet)
Ramey Gravel, thin.	
Disconformity.	
Older basin deposits:	
14. Gypsum	1.0
13. Claystone, green	1.2
12. Gypsum	.5
11. Claystone, green	2.0
10. Gypsum, like unit 2 below	3.6
9. Claystone consisting of three units: base white, middle green, top red	5.8
8. Gypsum; like unit 2 below	.4
7. Claystone, green, massive	2.6
6. Gypsum; like unit 2 below. Some selenite crystals 5 to 6 in. long	.4
5. Claystone, mostly green; greenish brown near weathered surface	2.0
4. Gypsum, like unit 2	1.5
3. Claystone, mostly green, some with red cast	2.0
2. Gypsum, selenite crystals form solid mass. Crystals have maximum length of about 1 in. Forms ledge	1.5
1. Claystone, reddish-brown, sectile, massive. Base not exposed; at arroyo level	4.5
Total measured thickness	29.0

Wherever older bedrock crops out in hills rising within the Hueco Bolson, coarse alluvium derived from these hills is interbedded with the finer alluvium from more distance sources. Thus, the basin fill surrounding these inliers in the same vertical section

FIGURE 46.—Older basin deposits, gypsiferous clay facies, exposed in an arroyo 2 miles southeast of Fort Quitman. Shown is horizontal lamination characteristic of this facies.

commonly contains conglomerate, sandstone, and claystone. The following stratigraphic section illustrates this relation.

Section of older basin deposits

[South edge of Hueco Bolson about 1½ miles east of Cox Ranch]

	Thickness (feet)
Younger basin deposits; top eroded.	
Disconformity.	
Older basin deposits:	
13. Siltstone, sandy. Poorly exposed	28
12. Sandstone and conglomerate, interbedded; beds 2 in. to 1½ ft thick, lenticular. All pebbles and cobbles of local origin; maximum size 3 in	10
11. Siltstone and silt, sandy; some claystone; buff and pink. Scours at top filled with overlying sandstone and conglomerate; maximum depth of scour about 6 in	9
10. Sandstone and conglomerate; caps low hill	3
9. Silt and siltstone, clayey, reddish-brown	6
8. Sandstone	3
7. Sandstone and conglomeratic sandstone	5
6. Silt and clay; some very fine grained sandstone. Poorly exposed	16
5. Sandstone and conglomerate	6
4. Sandstone, fine- to medium-grained; contains thin conglomeratic lenses; similar to unit 1 below	6

Section of older basin deposits—Continued

	Thickness (feet)
Older basin deposits—Continued	
3. Sandstone and conglomerate, interbedded in layers 1 to 1½ ft thick. Basal 1½ ft is conglomerate consisting chiefly of angular but smooth pebbles and a few rounded pebbles; average pebble size ½ in.; some 4-in. cobbles; pebbles all of local source; quartzite pebbles predominate; some crossbedding. Medium-grained sandstone contains some pebbles; thin even beds ⅛ to ¼ in. thick. Beds are lenticular; in places almost entire unit is conglomerate, elsewhere nearly all sandstone	6
2. Silt, buff and pink, and claystone, brown, silty. Wavy top with scours filled by overlying beds	4
1. Sandstone, medium-grained, well-cemented with calcareous cement; almost entirely quartz grains. Forms small ledge; base not exposed	3
Total measured older basin deposits	105

CONDITIONS OF DEPOSITION

The older Hueco Bolson deposits comprise alluvial-fan and playa deposits that filled a desert bolson. The character of the deposits indicates that the basin was a closed one here as well as farther to the north (Sayre and Livingston, 1945, p. 40–41). The origin of the basin that received these deposits is not known, although similar basins that probably received correlative deposits along the Rio Grande depression in New Mexico were formed in part by faulting (Bryan, 1938, p. 205–208; Denny, 1940a, 1940b, p. 94–95; Kottlowski, 1958, p. 48 and 51). No faults that may have formed the basin in the report area are recognized.

Streams heading in the mountains marginal to the basin built gravel fans as they entered the bolson. The poorly sorted massive fanglomerate was laid down during recurrent episodes of rapid deposition by ephemeral torrents, produced by heavy rains. As the streams spread down the fans, they lost competence by forking into distributaries and by loss of water by infiltration; the alluvium was therefore graded according to its distance from the mountains. Only the finest sediments reached the playas or ephemeral lakes in the lower reaches of the bolson. As the lakes disappeared by evaporation, much of the chemical load of the water was precipitated and settled along with the finest clay as crystals of calcite and selenite.

The source of the hundreds of feet of clay deposited in the basin is uncertain. Before the older basin deposits were laid down, a mantle of residual clay might have formed upon the surrounding uplands during a long interval of humid climate, or the very fine grained material may have been formed slowly during a more arid climate.

YOUNGER BASIN DEPOSITS

The younger basin deposits consist of fluviatile sand and gravel. The basal part is composed of gravel containing pebbles and cobbles of local origin mixed with others that must have come from more distant areas outside the local area. These exotic pebbles and cobbles are chiefly granite, quartz, quartzite, rhyolite, and other volcanic rocks unlike those exposed in the Quitman Mountains. The granitic rocks might have come from the Franklin Mountains near El Paso about 80 miles to the northwest along the Rio Grande or from a still more distant source. Nearly all the exotic pebbles are perceptibly smoother and better rounded than those from local sources. The largest stone observed was a cobble of red rhyolite 7½ inches long and 3½ inches across. The east limit of the area containing exotic pebbles is shown in figure 47.

The layer of exotic gravel and sandstone at the base of the younger basin deposits is well consolidated in places and is as much as 6 feet thick. Parts are crossbedded, the crossbedding generally dipping southeastward in the downstream direction of the Rio Grande. Most of the alluvium above the exotic gravel is fine- to coarse-grained buff or pink sand containing a few thin layers of clay and lenses of gravel which consist of pebbles and cobbles mostly of local origin.

The maximum measured thickness of the younger basin deposits is 65 feet. These deposits occupy a broad valley cut into the older basin deposits. Wherever the undercut banks of this ancient channel can be seen in section, it is clear that several score feet of the older basin deposits had been removed before the exotic gravels were deposited. The base of these gravel beds is along an irregular surface that still preserves the effects of scour and channeling (fig. 48).

The following stratigraphic section illustrates the relation between the older and younger basin deposits.

Section of older and younger basin deposits

[South side of Madden Arroyo, opposite Madden station]

	Thickness (feet)
Madden Gravel:	
7. Caliche	3
Disconformity.	
Younger basin deposits:	
6. Sand, coarse (in lower fourth) and medium to fine (in upper three-fourths); lentils of pebble gravel at bottom and top. In lower 6 ft pebbles are well rounded and of rock types foreign to the Sierra Blanca area. Pebbles at higher levels are more angular and of local origin, mostly limestone and scattered fragments of hornblende andesite porphyry. Gravel makes up less than 5 percent of total unit	46
5. Conglomerate and sandstone, crossbedded. Conglomerate of well-rounded pebbles and cobbles; consists of rock foreign to Sierra Blanca area; contains reddish-brown rhyolite, granite, quartz, quartzite, and a variety of volcanic rocks	6
Total measured thickness, younger basin deposits	52
Disconformity.	
Older basin deposits:	
4. Clay, silty, reddish-brown	16.5
3. Sand, cross-laminated	6.5
2. Breccia of polygonal-shaped flakes of mudstone as much as ½ in. across	1.5
1. Sand, fine-grained, crossbedded; contains abundant grains of pink feldspar; some parts cemented with calcite; base not exposed	18.0
Total measured thickness, older basin deposits	42.0

CONDITIONS OF DEPOSITION

The younger basin fill was deposited by a river flowing through the Hueco Bolson. After the stream had established its course across what had long been a basin of internal drainage, it cut into the older basin deposits and formed a flood plain. Channel deposits of exotic gravel were spread over this surface and mixed with the contribution of tributaries from the sides. Thereafter the flood plain was aggraded at

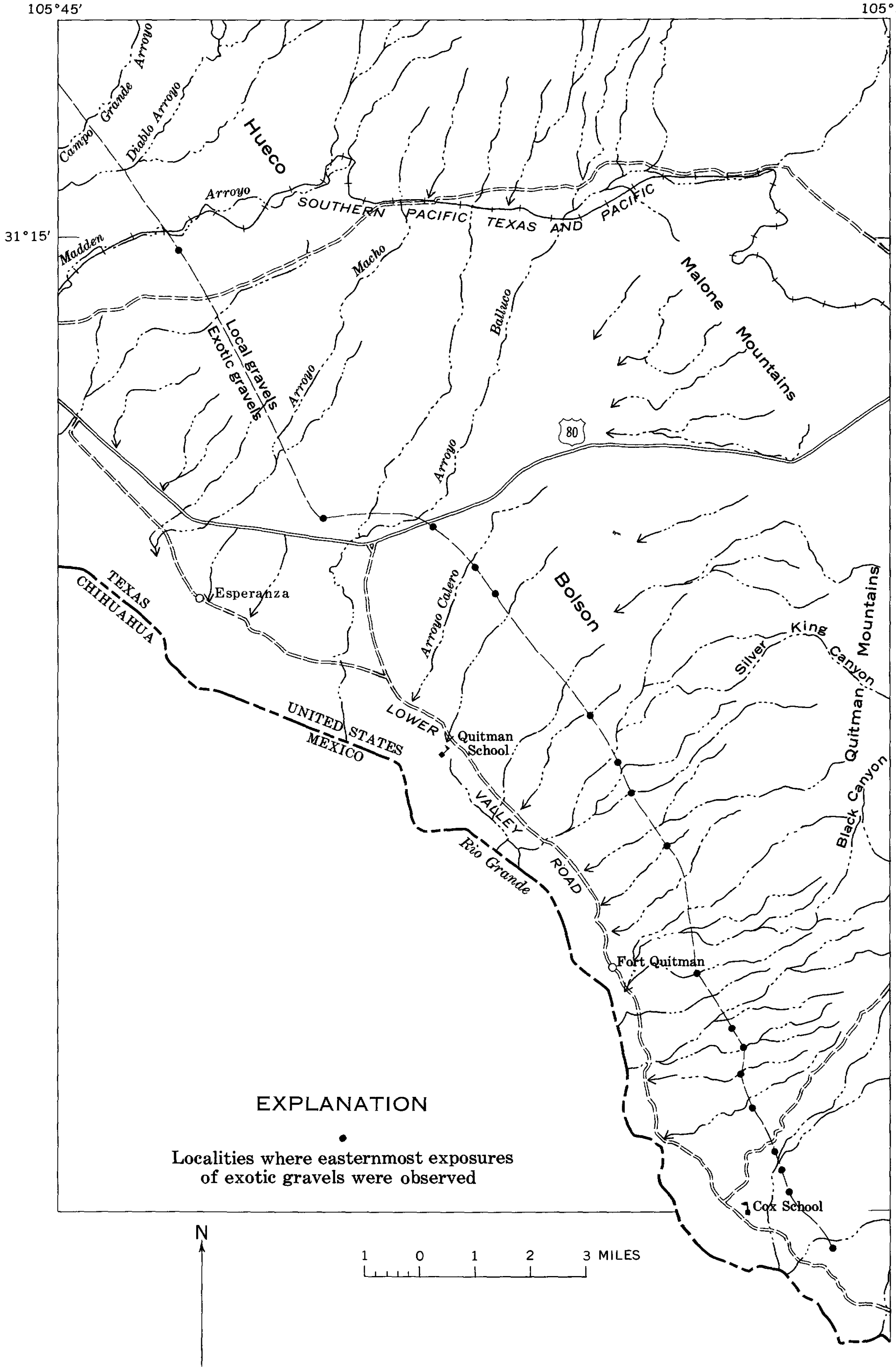

FIGURE 47.—Part of the Hueco Bolson showing east limit of exotic pebbles in gravel of younger basin deposits.

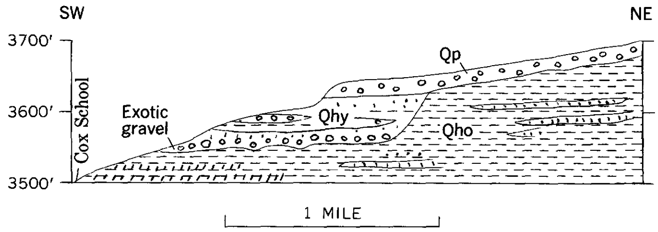

FIGURE 48.—Diagrammatic section showing the relation between older basin deposits (Qho) and younger basin deposits (Qhy) and gravel (Qp) on a pediment. Section is drawn along a line northeast from Cox School. (For lithologic symbols, see fig. 44.)

least 70 feet above its initial level. Presumably this river was the Rio Grande because there is no evidence that external drainage of the bolson has been interrupted since the exotic gravel was deposited.

The manner in which the Rio Grande became established in the Hueco Bolson cannot be determined in the Sierra Blanca area. Southeast of the mapped area, the Rio Grande crosses many bedrock ridges and mountains, any one of which might formerly have obstructed external drainage. These barriers could have been breached, and the river could have assumed its present course by being superimposed from a surface on the older basin deposits or by overflow and resultant downcutting as the basin was filled to the brim by sediment and water. Ponding and overflow at the south end of the basin has been suggested by Kottlowski (1958, p. 48). Superposition is indicated at the south edge of the mapped area, where the Rio Grande has cut a canyon through bedrock hills surrounded by the more easily eroded basin deposits. A fuller understanding of the history of the Rio Grande must await further studies both upstream and downstream from the Sierra Blanca area.

AGE AND CORRELATION OF BASIN DEPOSITS

The older basin fill is probably younger than middle Pliocene age, and the younger fill is probably early Pleistocene. Collectively, the older and younger fills may correspond to the upper part of the Stanta Fe Group in the Rio Grande valley of New Mexico.

W. S. Strain (1959) assigned a Blancan age to his unit B, the younger basin deposits of our report, from fossil collections that include *Equus* (*Plesippus*), *Nannipus*, *Testudo*, *Tapirus*, *Megalonyx*, and *Glyptodon* along Camp Grande, Diablo, and Madden Arroyos and Arroyo Balluco. Strain's collections are from the lower part of the younger deposits and below an ash bed that was correlated by Howard A. Powers (written commun., 1960) on a mineralogical basis with the Pearlette Ash Member of the Sappa Formation.

The beds of Blancan age were formerly placed only in the late Pliocene (Wood and others, 1941, pl. 1 and p. 31; Simpson, 1947, p. 481), but later evidence favors reassignment to include the Nebraskan Glaciation (including early part of the Aftonian Interglaciation by some writers) of the Pleistocene (Evans and Meade, 1945; Meade, 1945; Frye, Swineford, and Leonard, 1948, p. 521; McGrew, 1948, Elias, 1948; Frye and Leonard, 1957) or to the Aftonian (Hibbard, 1958a, p. 24). On the basis of the fauna contained in the younger basin deposits below the ash bed, these deposits are early Kansan age or older according to Strain (1959, p. 375), and the ash bed is late Kansan on the basis of correlation with the Pearlette Ash Member of late Kansan age (Hibbard, 1958b, p. 55). The occurrence of *Tapirus* and *Testudo* in these beds suggests that the climate was warm at the time of deposition of the younger basin deposits and that these deposits below the ash bed, then, might be pre-Kansan interglaciation or Aftonian (Strain, 1959, p. 375).

From his unit A, the older fill of our report, Strain (1959) collected *Testudo*, *Geomys*, *Nannipus*, *Sigmodon*, *Citellus*, and *Scalopus* and, based on the occurrence of *Testudo* and *Sigmodon*, concluded that this fill was probably deposited at a time of warm climate. He (Strain, 1959, p. 375–376) was less certain of the dating than for his unit B but believed that unit A could be Pliocene or perhaps a Pleistocene interglaciation, probably Aftonian. That both the older and younger basin deposits are Aftonian seems unlikely. Most important to the history, however, is the dating of the younger deposits and the indication that the Rio Grande started flowing through the Hueco Bolson during early Pleistocene time.

Similarities in topographic position, lithology, and mode of origin suggest that the basin fill may correspond to the upper part of the Santa Fe Group. Like the deposits of the Hueco Bolson, the Santa Fe is a complex accumulation of fanglomerate and finer grained clastic sediment of local origin and of subordinate playa deposits and gravel beds laid down in part by through-flowing streams. The deposits are further alike in that they are deformed and broken by faults, truncated by pediments, and associated with basaltic rocks. (For descriptions of the Santa Fe Group, see Bryan, 1938, p. 205–209; Denny, 1940a and b; Wright, 1946; Stearns, 1953, p. 472–475, 493–501.)

The Santa Fe Group is usually assigned a middle(?) Miocene to Pleistocene(?) age. Remains of *Plesippus* and *Rhyncotherium* collected from this formation near Socorro, N. Mex., indicate that the Santa Fe ranges up into the Blancan age (Wood and others, 1941, p. 31). On reclassification of the Blancan fauna, the Santa Fe would range in age from middle(?)

Miocene probably through the Nebraskan Glaciation and Aftonian Interglaciation of the Pleistocene. Integration of basins along the Rio Grande depression thus may have been accomplished by the ancestral river no earlier than the beginning of the ice age and not during the Pliocene as commonly supposed. Resolution of this problem waits upon discovery and identification of fossils in the axial gravels within the Santa Fe along the upper reaches of the Rio Grande depression. Certain rushes collected from axial gravels of the San Acacia area, New Mexico (Denny, 1940b, p. 93), are reported by Darrah to be "of almost modern aspect" and are perhaps more suggestive of a Quaternary than a Tertiary age.

SEDIMENTARY AND IGNEOUS ROCKS OF QUATERNARY AGE

POSSIBLE VOLCANIC NECKS IN THE HUECO BOLSON

South of the Malone Mountains in the Fort Quitman quadrangle, two conical hills covered with basalt boulders rise 60 to 120 feet above the level of the Hueco Bolson. No bedrock is exposed on the smaller hill, north of U.S. Highway 80, but quarries in the larger hill south of the highway show that the hill is a mass of igneous rock. Both hills are probably volcanic necks that have penetrated the alluvial fill of the bolson; they are probably younger than the older basin deposits and older than the gravel caps, such as the surrounding Gills Gravel (table 11).

As seen in 1949, the quarry face along the southeast side of the larger hill was about 150 yards long and 30 feet high. Most of the rock exposed in the face is amygdaloidal basalt obscurely layered in horizontal or gently inclined units 10 to 20 feet thick. In places, elongate amygdules are parallel to the crude layering. Irregular vertical pipes of basaltic breccia cut the stratified rock at intervals of 60 to 70 feet. The contact between the basalt and the basin fill was not exposed. However, the rounded plan of the hill, its elevation above the surrounding alluvial plain, the breccia pipes, and the absence of lava in the older alluvium of this region suggest that the basalt marks a volcanic neck. We could not determine whether a smaller outcrop of basalt directly to the south possibly marks a subsidiary vent.

Specimens collected from the quarry are medium-gray to medium dark-gray (*N*4 to *N*5) fine-grained basalt porphyries. Phenocrysts of olivine, averaging less than 1 mm across and mostly altered to iddingsite, are set in a felted matrix of labradorite laths, with abundant fine intergranular iddingsite. Amygdules are made of interlocking crystals of quartz and calcite; the calcite is concentrated toward the centers.

GRAVEL AND CALICHE ON SURFACES OF EROSION

Five erosion surfaces capped with gravel, caliche, or both occur in the Hueco Bolson. The gravels of the different surfaces are of about the same lithology, but differences in elevation, slope, and degree of weathering indicate that they are of different ages. The gravel is of local origin, so that deposits of the same age differ from place to place, all of them being finer away from the mountains and toward the Rio Grande. Bedding is generally obscure, but locally the gravel is evenly stratified or is in lenticular beds containing moderately well sorted fragments.

The gravels were deposited both on pediments and on terraces, which grade into each other. Gravel of a given age caps both kinds of landforms, and all the gravels are mapped according to age rather than to occurrence on a specific type of landform. The pediments are cut chiefly on basin deposits, though locally at mountain edges on bedrock. In most places, these pediments truncate the basin deposits at low angles because the pediments slope gently and the basin deposits are almost horizontal. Where the basin deposits are deformed, the angular unconformity between them and the pediment gravel is pronounced.

The height of any of the gravels above the arroyo floors varies widely, because the arroyos have different gradients from those of the pediments or terraces. In general, the gravels lie 10 to 300 feet above the present flood plains.

Calcium carbonate in some of the limestone gravel has been leached and deposited as masses of secondary calcium carbonate or caliche. Where the entire cap is made of caliche, the geologic map is marked by special symbols (for example, Gills Gravel capped with caliche, pl. 1). The middle three of the five surfaces have prominent caps of caliche in places, but the oldest and the youngest do not. The maximum thickness of the caliche is about 3 feet. In most of the gravels, even where a thick crust has not formed, white films of calcium carbonate coat pebbles and cobbles, particularly in the upper few feet of the deposit. Limestone pebbles in the caliche vary widely in degree of solution. Some have been only slightly etched on top; others have been faceted on their upper surfaces; and still others have been reduced to thin, flat strips of limestone, some of which have an open space above that shows the outline of the pebble and a coating of caliche on the underside.

The gravels on the surfaces of erosion are here named the Miser, Madden, Gills, Ramey, and Balluco Gravels, in order of decreasing age. Data on these gravels are summarized in table 11.

TABLE 11.—*Summary of data on gravel of Quaternary age on surfaces of erosion*

Formation	Type locality	Composition of fragments	Size and shape of fragments	Thickness	Height above arroyos	Relation to next youngest gravel
Balluco Gravel	Along Arroyo Balluco south of U.S. Highway 80.	Limestone, sandstone, quartzite, conglomerate, and extrusive and intrusive igneous rocks.	Sand to boulders, angular to subrounded; some clay and silt.	6 in. to 20 ft; locally veneer is no thicker than diameters of fragments.	Generally 10 to 40 ft; in places almost at stream level.	
Ramey Gravel	One mile northeast of Ramey Station on Southern Pacific railroad track.	Limestone, sandstone, quartzite, conglomerate, and extrusive and intrusive igneous rocks; many basalt pebbles and cobbles southwest of basalt hills near U.S. Highway 80.	Sand to boulders, angular to subrounded; some clay and silt.	1 to 25 ft.	10 to 70 ft.	5 to 20 ft above.
Gills Gravel	West side Arroyo Calero about 2½ miles north of Gills Ranch.	Limestone, sandstone, quartzite, and extrusive and intrusive igneous rocks; some claystone in thin layers and angular fragments.	Sand to boulders, angular to subrounded, mostly smoothed edges; some clay.	1 to 25 ft.	60 to 80 ft.	5 to 15 ft above.
Madden Gravel	South side Madden Arroyo in northwest corner Fort Quitman quadrangle.	Limestone, sandstone, quartzite, conglomerate, and extrusive and intrusive igneous rocks, all from local sources; some claystone in layers and angular fragments, probably derived from older basin deposits.	Sand to boulders, angular to subangular; some clay.	1 to almost 30 ft.	10 to 110 ft.	5 to 20 ft above Gills and Ramey gravels where adjacent to them.
Miser Gravel	Miser Arroyo along southwest edge of southern part of Quitman Mountains.	Chiefly limestone, sandstone, and quartzite derived from nearby parts of Quitman Mountains; less common particles of extrusive and intrusive igneous rocks.	Sand to boulders, angular to subangular; commonly smoothed edges.	1 to 20 ft.	200 to 300 ft.	

The gravelly deposits on the erosion surfaces appear to be of Quaternary age. If the younger basin fill is no younger than Kansan, the gravels are post-Kansan because they rest upon surfaces that truncate the younger fill. In the absence of fossils or other means of dating the gravels, the relation to the main Pleistocene sequence or even to the pediments in the upper Rio Grande depression of New Mexico would be merely speculative. Presumably the repeated trenching and pedimentation of the bolson and formation of the terraces were related to fluctuations in the rate of downcutting along the Rio Grande. We cannot be sure of the cause of these fluctuations, however, until much more extensive studies are made along this river. The fluctuations may be related to climatic changes during the Pleistocene, or they might be tectonically controlled. By a mechanism recently suggested by Hack (1960), however, neither climatic nor tectonic changes are required to produce such a series of surfaces. According to Hack, the cutting of a series of pediments is a continuing process dependent largely on contrasts in rock resistance. He postulates that streams rising in the basin perform most of the erosion while those heading in the mountains transport gravel and deposit it in front of the mountains so that areas along these streams are aggraded and protected by a gravel armor until an eroding basin stream destroys it. This process is similar on a large scale to that described for the gravel-covered area at the mouth of Black Canyon. Under Hack's concept, no cyclic changes or times of stabilization of the local base level are required to form a series of erosional surfaces.

TERRACE DEPOSITS ALONG RIO GRANDE

Two alluvial terraces border the flood plain of the Rio Grande, and the higher one extends along some of the tributary arroyos. The higher and older terrace is about 40 feet, and the lower, 15 to 20 feet, above the Rio Grande flood plain. The relation of the terrace deposits to other units of Cenozoic age is shown on figure 49.

The alluvium in the terraces consists chiefly of coarse sand and gravel and some fine sand, silt, and clay. The pebbles in the gravel are angular to moderately well rounded and are mostly half an inch or less in diameter, although some are as much as 6 inches. These terrace deposits are dated only as younger than the Balluco Gravel and older than the alluvium along the Rio Grande and the arroyos.

ALLUVIUM AND COLLUVIUM

Alluvium and colluvium form an extensive cover in parts of the report area. As mapped, the alluvium consists of material deposited along the modern streams, and the colluvium consists of slope-wash deposits, soil-creep deposits, talus, and some thin alluvial deposits. Colluvium is separated into two units: (1) older colluvium and (2) mixed and undifferentiated alluvium and younger colluvium.

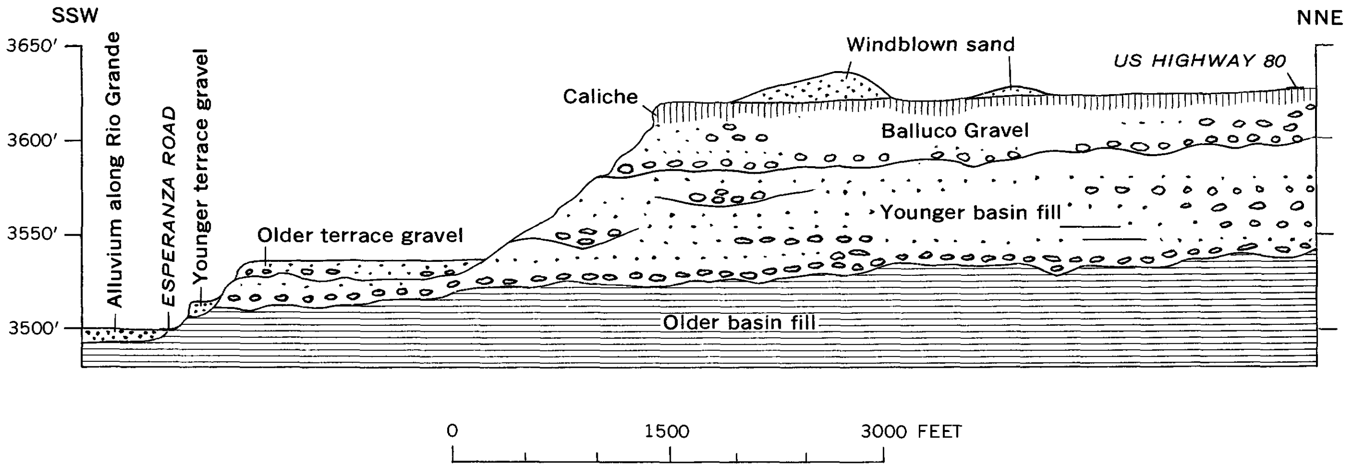

FIGURE 49.—Relations between seven rock units of Cenozoic age, as exposed at Esperanza.

OLDER COLLUVIUM

The older colluvium remains only on steep slopes and is confined to the general area of the Sierra Blanca peaks. It consists of angular fragments chiefly of cobble size or larger. On the north side of Little Blanca Mountain, the colluvium forms a talus that has crept down the slope by gravity.

These deposits are now being dissected. Some of the hills capped with remnants of colluvium stand more than a mile from the mountains that supplied the fragments. The outliers on hills near Ramsey Tank, northeast of Triple Hill, and on hills north of Round Top are definitely older than the Madden Gravel and probably younger than the basin fill in the Hueco Bolson. The deposits probably formed at a time when frost action was more pronounced than it is today, possibly in the late Pleistocene.

UNDIFFERENTIATED ALLUVIUM AND YOUNGER COLLUVIUM

The undifferentiated alluvium and younger colluvium cover extensive areas around the margins of hills and mountains. Like the alluvium along flood plains of arroyos in the east half of the Sierra Blanca area, these deposits consist of silt and sand and larger angular fragments of the local bedrock. Some of the coarser materials, however, have been moved mainly by gravity and rill wash from steeper slopes near the margins of bedrock exposures. The size of the fragments decreases away from the bedrock sources. These mixed colluvial and alluvial deposits are generally not subject to wash or flood at present, although sheet floods occasionally move over some of them.

The thickness of the undifferentiated deposits has not been determined in most places, although the water wells on the Diablo Plateau penetrated as much as 40 feet of these deposits before striking the bedrock. Adjacent to some of the mesas on the plateau, the colluvial deposits are probably several tens of feet thick.

These deposits are still accumulating, but the oldest parts probably began to be deposited during the Pleistocene Epoch.

ALLUVIUM

Widespread deposits of alluvium form the flood plains of the Rio Grande and of the arroyos. These deposits along the river consist of material derived both from local sources and from sources outside the report area, whereas those along the arroyos consist of material derived only from local sources.

The alluvial deposits of the Rio Grande flood plain are sand and silt, which contain scattered lenses of gravel or clay. Much of the material is a poorly sorted mixture of sand, silt, and clay. In its natural course, the river is meandering, as shown by the many cutoffs and sloughs which marked its former positions. As most of the flood plain is cultivated, shifts in the course of the river not only made irrigation difficult but also created legal problems related to the international boundary between Mexico and the United States. Accordingly, the course of the river has been artificially straightened, and the banks have been covered with riprap.

Alluvium under the flood plains of the arroyos consists of lenticular beds that range in texture from clay to boulders, derived from the bolson and its bordering uplands; much of the alluvium has been introduced into the arroyos by caving of banks during and after floods. Most of the alluvium is no more than a few feet thick, but in places it is almost 50 feet thick. The arroyos of the Hueco Bolson have relatively even floors in which the main water course is incised a few feet to 10 feet below the flood-plain surfaces. During most rains the water flows along the principal channel and sinks rapidly into the underlying sand and silt. During heavy rains the water may cover the entire width of the flood plain. Where the arroyos join the Rio Grande flood plain, low alluvial fans have been constructed. In most places, the river has eroded the edges of these fans to form low scarps at the margin of the Rio Grande flood plain.

McConnell and Crim (1941) found hearths and pottery buried in the flood plain of Campo Grande Arroyo in the Finlay Mountains. In their report, the pottery has been dated as probably no older than 1150 A.D., and the alluvium has been correlated with the Kokernot Formation of Albritton and Bryan (1939) of the Davis Mountains area of Trans-Pecos Texas.

WINDBLOWN SAND

Windblown sand covers broad areas in the west quarter of the report area. The two largest dune fields are remarkably unlike in their topographic situation, one being on the higher part of the Diablo Plateau and the other in the lower reaches of the Hueco Bolson. These fields do not connect across the rimrock of the plateau, but both are parts of a larger complex of eolian deposits centering in the bolson farther to the northwest.

The sand dunes on the Diablo Plateau are largely inactive, except around blowouts or the heads of gullies, and are covered with cactus and scrub. The sandy surface is characterized by smoothly contoured hillocks rising 10 to 30 feet above irregular undrained depressions. Samples of sand collected near Granite Mountain are made up of fine subangular to subrounded quartz gains, many of which have a thin coat of iron oxide that imparts a light-brown color to the sands.

Stabilized dunes similar to those on the plateau cover the broad divides between arroyos in the Hueco Bolson, especially below an altitude of 4,100 feet and west of Arroyo Balluco, and occur from place to place on the Madden, Ramey, and Balluco Gravels. Samples collected along Arroyo Balluco are light brown, like the sand on the plateau, but the grains are subrounded to well rounded and mostly medium to coarse.

Patches of windblown sand also border the flood plain of the Rio Grande and extend for short distances up tributary valleys. Many of the dunes are active or are only partly anchored by vegetation; much of this sand appears to be reworked from alluvial deposits of the flood plain.

Although the eolian deposits are shown on the geologic map by a single symbol, the sands indicate at least two episodes of accumulation. Active dunes along the flood plain of the Rio Grande, in blowouts, and along the floors and sides of arroyos are obviously products of the present dry climate. The fields of inactive dunes on the Diablo Plateau and on the flat-topped divides in the Hueco Bolson are relicts of earlier episodes of dune building. These dunes have been modified by creep and wash and are being destroyed by headward erosion of gullies.

Probably the dune fields themselves contain deposits of different ages. If the alternate channeling and filling of the Hueco Bolson, after deposition of the younger basin deposits, was ultimately controlled by shifts from moist to dry climates, drifting of the sands probably occurred periodically during the drier periods; however, a systematic search was not made for such evidence. Those dunes on the broad divides west of Arroyo Balluco are obviously younger than the Balluco Gravel, and the similar dunes on the Diablo Plateau may be younger also, but no evidence on which to establish their age has been found. The association of pottery and artifacts with dunes along Arroyo Balluco near Madden and elsewhere suggests that archeological studies might amplify and refine the stratigraphy of the eolian deposits.

STRUCTURE

THE TECTONIC DIAGRAM

The tectonic diagram (pl. 7) shows the principal structural features of the Sierra Blanca area and illustrates the structural contrast across the boundary between the stable platform and the mobile belt. Contours drawn on the top of the Cox Sandstone depict the folds and domes in the northeastern part of the area; lines indicate the faults and fold axes in the more complexly deformed beds in the thrust blocks to the southwest. As the Cox Sandstone and the Finlay Limestone are intertonguing units, the contours are not on a single stratigraphic horizon, but the distortions resulting from this variation are probably inconsequential.

Some of the intrusive igneous bodies occupy fractures, and others have deformed the sedimentary rocks. The laccolithic masses of Sierra Blanca Peak, Little Blanca Mountain, Round Top, and Little Round Top have their bases well above the top of the Cox Sandstone and did not deform the strata at the contoured horizon.

DOMES AND BASINS OF THE DIABLO PLATEAU AREA

The gently dipping strata of the Diablo Plateau are deformed into domes, anticlines, and basins. Along the southwest margin the beds bend under the hanging wall of the Devil Ridge thrust. Small folds and structural basins are superimposed on this flexure around the north end of the Quitman pluton.

THE DIABLO PLATEAU PROPER

Over most of the Diablo Plateau, the Cretaceous strata dip less than 2°, but the dip slopes and cliffy ledges of the Finlay Limestone disclose reversals of dip related to open folds trending N. 60°–80° W. From south to north, the principal folds are (1) an anticline extending from the Gunsight Hills southeast to Round Mountain, where the axis curves northeastward and the fold is broken by a normal fault striking west-northwest, (2) a syncline that merges northwestward with a homoclinal structure which slants upward toward Granite Mountain, and (3) a shallow syncline in the northeast corner of the mapped area. The two synclines are separated by a structural terrace.

A dome at the Gunsight Hills appears to lie along the axis of the Round Mountain anticline, although in the saddle between the two hills the dips are so gentle that reversals are difficult to detect. Near the Gunsight Hills the vertical closure on the top of the Cox Sandstone is about 300 feet. The resemblance between the shape of this dome and the domes of the Finlay Mountains, which were formed by intrusion of igneous bodies, suggests that the dome of the Gunsight Hills may have been uplifted by an igneous intrusion, but a well drilled to a depth of 2,705 feet did not penetrate igneous rock.

The south edge of the Diablo Plateau is a southward-facing topographic escarpment formed principally of Cox Sandstone. West of Round Mountain this edge consists of discontinuous scarps lying en echelon. East of the report area, where Permian and older rocks are exposed, the scarp is higher and more continuous (King, 1949; King and Flawn, 1953, pl. 3).

Several short normal faults were mapped in the vicinity of the scarps, but none were observed in the plateau just to the north. This fact suggests that in places the scarps are related to faults, but if so, these faults are largely hidden beneath the widespread cover of alluvium. Faults appear to decrease in size and number westward across the area, as has been indicated previously (King, 1949). A fault can reasonably be inferred to extend along the south side of the escarpment east and west of Round Mountain and is apparently the western continuation of the South Diablo fault of the area farther east (King and Flawn, 1953, p. 112–117, pls. 2, 3). In places along the lower escarpment, we have mapped faults en echelon to the southwest but were not able to establish their continuity. Near Mock Tank and Sand Tank, this scarp seems to have been produced more by flexing than by faulting.

The more persistent faults strike west-northwestward. Most are nearly vertical, and few have throws of as much as 50 feet. The greatest observed displacement (140 feet) is on a fault 5 miles northwest of the Finlay Mountains.

MARGINAL BELT SOUTH OF THE DIABLO PLATEAU

Along the south margin of the plateau, in a belt 7 miles wide, Cretaceous strata are flexed down toward the southwest; the south border of this belt is the trace of the Devil Ridge thrust. Small folds and domes are superimposed on the flexure, and the strata are broken by faults trending west to northwest.

Between Sierra Blanca Peak and the Quitman Mountains, a syncline plunges southeastward beneath the hanging wall of the Devil Ridge thrust (pl. 8). This fold broadens toward the northwest and disappears along the east side of the Finlay Mountains.

Faults are numerous in the marginal belt, but none of them persists for more than a few miles. Collectively the faults describe a broad arc, convex toward the northeast. In the Finlay Mountains, along the western part of the arc, the more persistent faults strike westward. Near Sierra Blanca and Texan Mountain, they strike N. 30°–55° W. The fault passing directly north of Texan Mountain is the largest and has a throw of about 900 feet. Most of the faults are downthrown on the northeast.

Many faults shown on the tectonic diagram (pl. 7) are in areas covered by Cenozoic deposits, and their presence is inferred from nearby outcrops and projections of the structure contours. Very likely there are many more covered faults than are shown.

Three small thrusts in the marginal belt have displacements of less than 50 feet. One that is about 3 miles south-southwest of the Gunsight Hills dips south at a low angle, and two on Flat Mesa dip southwestward at low angles. These thrusts mark the northernmost limit of thrusting beyond the Sierra Madre Oriental.

UPLIFT CAUSED BY INTRUSIONS OF THE IGNEOUS BODIES

The structural dome at Triple Hill and the two in the Finlay Mountains were formed above masses of intrusive rock. At Triple Hill part of the intrusive core is exposed, and the tilted sedimentary rocks above it are well exposed on the west and southwest flanks. A well drilled on the east dome in the Finlay Mountains (well 3, pl. 1) entered igneous rock at a depth of 1,575 feet. The radial pattern of dikes on the west dome of the Finlay Mountains suggests that the doming was caused by an underlying magma body that was parent to the dikes.

Steeply dipping beds on the flanks of the intrusive bodies at Sierra Blanca, Little Blanca Mountain, Round Top, and Little Round Top indicate that the sedimentary rocks were domes over each of these laccolithic bodies. Possibly the domes southeast of Sierra Blanca Peak were also formed by intrusion. The abundant sills south of Flat Mesa make this area similar to the east dome of the Finlay Mountains and thus suggest intrusive doming, but no drill data are available to confirm it.

The Quitman pluton is a discordant body that not only cut across adjacent strata but also dragged and uplifted them. Uplift of beds near the northeast edge of the pluton reversed the general southwestward dip of the beds and formed a syncline between the Quitman Mountains and Sierra Blanca Peak.

THRUST FAULT BLOCKS OF THE SIERRA MADRE ORIENTAL

The area southwest of the Devil Ridge thrust is divided into three blocks by northwestward-trending thrust faults (pl. 9). Complexity of structure increases to the southwest from thrust block to thrust block.

DEVIL RIDGE THRUST BLOCK

DEVIL RIDGE THRUST

The trace of the Devil Ridge thrust forms the northeast edge of the Sierra Madre Oriental. This trace trends about S. 40° E. across the mapped area for 16 miles and continues southeastward along Devil Ridge (Smith, 1940, p. 630 and pl. 1) and into the Eagle Mountains, where it disappears beneath lava (Gillerman, 1953, p. 41-42, pl. 1; Smith, 1941, p. 75–76, pl. 1). It therefore has a total known length of about 30 miles.

Areal relations of the stratigraphic units suggest that northeast of Yucca Mesa the stratigraphic throw may be about 4,500 feet. The dip of the thrust probably differs from place to place along the strike. Thus, different formations in the lower plate occur at the fault from place to place, but wherever the fault is exposed, the gliding surface is on silty, shaly, and sandy beds of Late Cretaceous age.

The fault is well exposed along the base of a hogback about 3¾ miles east of the mapped area, where the Yucca Formation is thrust over the Eagle Ford Formation and the fault surface dips 55° SW. The stratigraphic throw here is almost 5,900 feet. A mechanical reconstruction based on the dip of the beds, the dip of the fault, and the stratigraphic throw indicates a minimum shortening or horizontal displacement of about 4½ miles (Smith, 1940, p. 630). For about 6 feet beneath the fault, the beds of the Eagle Ford (probably equivalent to undifferentiated Upper Cretaceous rocks of the present report) are crumpled and dragged into small folds. Small asymmetric folds, some overturned to the northeast, also occur in the Eagle Ford Formation 100 feet or so below the thrust.

The thrust also crops out at the Etholen Knobs and on hills to the south. Here the fault and the strata beneath have been warped into a syncline by uplift of the Quitman pluton, as first recognized by Baker (1927, p. 41; 1930, pl. 1). Erosion has reduced the overthrust block to klippen at the Etholen Knobs, where resistant beds of the Etholen Conglomerate rest on less resistant beds of Early Cretaceous age. The stratigraphic throw in this vicinity is about 6,500 feet. Although natural exposures of the fault are lacking, its position may be determined within a few feet. Locally, the Upper Cretaceous strata in the footwall are bent into small asymmetric or overturned folds and have steep or overturned limbs on the northeast.

West of Bluff Mesa, the Devil Ridge thrust presumably joins the Red Hills thrust, and the two continue northwestward as a single fault.

STRUCTURE WITHIN THE BLOCK

Strata within the Devil Ridge thrust block are mainly homoclinal and have southerly or southwesterly dips of less than 30°, although local dips are as steep as 55°. The strikes range locally from northwest to northeast, but continuity of formations along Devil Ridge, Yucca Mesa, and Bluff Mesa demonstrates the essential structural simplicity within the block. A shallow syncline crosses the west side of Bluff Mesa. An overturned anticline and syncline on the ridge southwest of Devil Ridge probably developed by drag beneath the Red Hills thrust.

Except for a small thrust near the southeast end of Devil Ridge, all faults within the block are normal. These faults strike northwestward and northeastward and are mostly downthrown to the northeast or northwest. Although some of the faults have curved traces that suggest low dips, all observed dips are steep or nearly vertical and indicate that the curves are real and not due to topography. The greatest throw observed is 280 feet, on a fault near the east side of Yucca Mesa; throw on the other faults ranges from 10 to 230 feet. In places, one fault ends against another without offset, and all the faults are probably of the same age.

A broad brecciated zone is exposed in the pass between Bluff Mesa and the lower hill to the west. Blocks and slices of rocks from the Etholen, Yucca, Bluff Mesa, Cox, and Finlay Formations are jumbled together in a rectangular area about 1,000 feet wide by 2,000 feet long. Despite the width of this zone, the vertical displacement of the beds on opposite sides does not exceed 300 feet. The trend of the zone cannot be established directly but is limited by the bearing of the pass itself and is probably near N. 10° E. Previously published maps (Moody and Hill, 1956, fig. 12; Huffington, 1943, pl. 1) show a fault trending north-northwestward through the pass. The great breadth of the breccia, the small vertical displacement on opposite sides, and the wide stratigraphic range of blocks and rock slices in the breccia suggest major strike-slip faulting.

RED HILLS THRUST BLOCK

RED HILLS THRUST

The Red Hills thrust trends N. 40°–45° W. about 18 miles across the Sierra Blanca area and extends at least 2 miles beyond the east boundary of the area (Smith, 1940, pl. 1).

The thrust is exposed only in the southeast corner of the area, in the Red Hills and along Back Ridge to the northwest. In places, the fault zone is as much as 300 feet wide and consists of a series of rock slices made up of randomly oriented blocks of limestone and conglomerate repeated along subsidiary thrusts. Here the Yucca Formation is thrust over the Cox and the Finlay, which are folded and overturned to the northeast; near the northwest end of the outcrop the thrust crosses the axis of one of these drag folds.

The thrust dips southwest at angles as low as 22° and has a stratigraphic throw of about 4,000 feet. A reconstruction of the fault and the overturned anticline broken by it indicates that the dip-slip displacement is slightly less than 2¼ miles.

Northwest of the supposed junction between the Red Hills and Devil Ridge thrusts, about 2 miles northwest of Bluff Mesa, the Bluff Mesa Limestone and the Yucca Formation are thrust over beds at least as young as the rocks of Washita age, whereas along the Red Hills thrust to the southeast, the Bluff Mesa Limestone (or perhaps the Yucca Formation) is thrust over beds probably no younger than the Cox Sandstone. This difference in stratigraphic throw suggests that the Devil Ridge thrust, and not the Red Hills thrust, carries most of the displacement in the country northwest of Bluff Mesa.

STRUCTURE WITHIN THE BLOCK

In contrast to the homoclinal structure in the Devil Ridge block, the strata in the Red Hills thrust block are deformed into many folds, some of which are overturned. Many wrinkles in the strata cannot be shown adequately on the scale of the geologic map and the tectonic diagrams. Most of the fold axes trend northwestward, although locally, as on Double Hill, their trend is more northerly. Minor wrinkles on the limbs of some folds make the structure more complex than indicated on plate 7; many of these small folds are in the Bluff Mesa Limestone on the hill west of Double Hill, and disharmonic minor folds are on Bug Hill.

Near the center of the southern part of the Quitman Mountains, the principal structure is an anticline trending north-northwestward. Anticlines and synclines in low hills along the east side of the moutains are mostly short, although the axes of a few extend to the surrounding alluvium and therefore may persist for greater distances.

All faults observed in the Red Hills thrust block are normal and trend either northwestward along the strike of the block, or northeastward, at right angles to it. Most of them are steeply inclined to vertical, although some have dips as low as 55°. Displacements range from 10 to almost 800 feet.

The largest fault in the block is a persistent strike-fault that has a throw of almost 800 feet on the east side of the southern part of the Quitman Mountains. Rocks of Washita age are downthrown on the east and abut against the Finlay Limestone on the west. More faults than are shown on the maps probably follow the east slope of the Quitman Mountains, but they were not recognized because the slopes are covered with rubble, and strike faults are difficult to detect in the massive limestone beds.

QUITMAN THRUST BLOCK

QUITMAN THRUST

The Quitman thrust, named by Huffington (1943, p. 1024), trends N. 15°–20° W. through the southern part of the Quitman Mountains. It can be traced for about 5½ miles in the southern part of the Sierra Blanca area, probably continues northward beneath surficial deposits at least 5 miles more (pls. 1 and 7), and apparently continues southeastward beyond the map area at least 10 miles (Baker, 1927, pl. 1). It therefore has a probable minimum length of 20 miles.

The Quitman thrust breaks across a large overturned anticline, whose axis is in the Hueco Bolson.

FIGURE 50.—Quitman thrust on east side of southern part of Quitman Mountains. View is southward from flat east of Quitman Gap. Beds in lower plate of fault (left) are in Cox Sandstone (Kc); beds in upper plate of fault (right) are overturned Bluff Mesa Limestone (Kb), which forms cliffs and most of the slope below, and overturned thin Cox Sandstone, which forms sloping bench just above thrust.

Along most of the fault trace, overturned beds of the Cox Sandstone in the upper plate are thrust over a normal sequence of beds of the Cox in the lower plate, but for a short distance inverted beds of the Bluff Mesa Limestone form the upper plate (fig. 50).

The thrust surface is exposed in only a few places. Locally, a breccia zone 30 to 40 feet thick marks the course of the thrust surface along the steep and rubbly slopes, but elsewhere the break seems to be fairly sharp and there is little breccia. Where strata of similar lithology are juxtaposed, the fault must be located by slight differences in the attitudes of the beds or by distinguishing overturned from normal sequences by reference to crossbedding. The fault is generally more easily visible from the distance than closeup because the angular differences in bedding are plainer. At the few places where attitudes could be measured, the thrust dips 20°–30° W.; this low dip must be general, as indicated by the sinuous trace of the fault. Reconstruction of the fault and the overturned anticline broken by it suggests that that the dip slip is a little less than a mile in the area about 2 miles southeast of Quitman Gap.

A klippe that caps a high ridge in the southeastern part of the mountains is made up of overturned Finlay Limestone that dips only 10°; this fact suggests that the broken anticline may have been recumbent. The fault beneath the klippe dips westward at only a few degrees and hence is much flatter than it is farther westward. The klippe is underlain by rocks of the Finlay Limestone on the west and south sides and by rocks of the Kiamichi Formation and of Washita age on the east and north sides.

STRUCTURE WITHIN THE BLOCK

Nearly all the exposed rocks in the Quitman thrust block are on the inverted northeast limb of the overturned anticline. Overturning is indicated by reversal of fossil zones, upward convexity of laminae in crossbedded sandstone, inverted ripple marks, and atti-

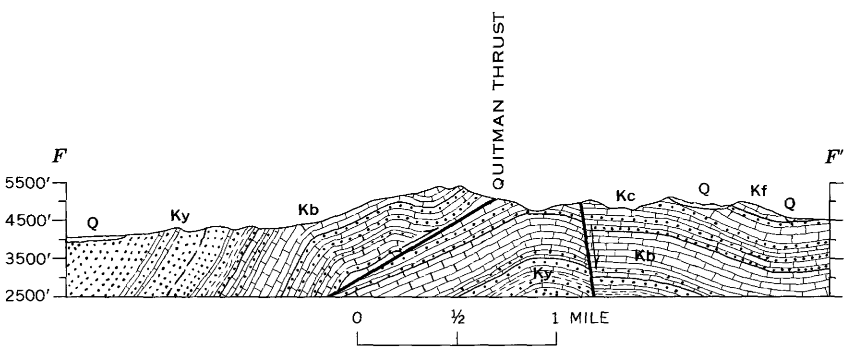

FIGURE 51.—Structure section, across southern Quitman Mountains, showing Quitman thrust and beds overturned more than 180° in the Quitman thrust block: Q, Quaternary deposits; Kf, Finlay Limestone; Kc, Cox Sandstone; Kb, Bluff Mesa Limestone; Ky, Yucca Formation. Location of section is shown on plate 1.

tudes of fracture cleavages. In places, the beds are overturned more than 180° and dip eastward, forming folds in the overturned limb (fig. 51).

On the west side of the northern part of the Quitman Mountains, the Bluff Mesa Limestone is folded into an anticline that has a curved axis, concave to the east. This is the Thirsty Dog anticline of Huffington (1943, p. 1021), who considered that the east limits may have been steepened during subsidence of the Square Peak Volcanics (Square Peak Volcanics Series of Huffington, 1943) to the east.

In the hills in the small southern projection of the mapped area, a normal sequence of beds in the Bluff Mesa Limestone dips westward. Another isolated outcrop of westward-dipping Bluff Mesa strata is on a line with these hills and is northeast of the Cox school. The Bluff Mesa Limestone is evidently repeated by folding or faulting beneath Cenozoic deposits between these outcrops and the Quitman Mountains.

Normal faults in the Quitman thrust block are all small. Most of them have throws of less than 30 feet and trend northeastward, at right angles to the strike of the beds and the thrust. Many of the limestone beds contain veinlets of calcite 4 to 6 inches long, which fill fractures that trend eastward. These fractures form northeastward-trending belts roughly parallel to the normal faults. A group of dikes of this same northeast trend cuts through both the lower and upper plates of the Quitman thrust.

THRUSTS BENEATH THE CENOZOIC COVER OF THE HUECO BOLSON

None of the three major thrusts is exposed west of the Quitman Mountains, although by projection the Devil Ridge thrust should extend into the Hueco Bolson beneath the cover of younger alluvial deposits between the Malone and Finlay Mountains, approximately along the dotted line shown on the geologic map (pl. 1).

Logs of wells drilled in the bolson clearly show that at least one major thrust fault, presumably the Devil Ridge, extends to and perhaps beyond the west edge of the mapped area. The Haymon Krupp Oil and Land Co. Thaxton 1 well, directly west of Campo Grande Mountain, crossed a thrust fault at a depth between 1,375 and 1,404 feet. The Briggs 1 well,[6] drilled by the same company at the northwest end of the Malone Mountains, crossed a similar fault at a depth of about 790 feet. The stratigraphic units penetrated below the faults are in normal sequence and are remarkably alike (Cannon, 1940). Interpretive summaries of the sample logs are given in figure 52.

Assuming that the Finlay Limestone is 240 feet thick in this area and the Cox Sandstone 700 feet, the thicknesses drilled in the two formations would require that the dips be 12°–25° at the Thaxton well and 25°–30° at the Briggs well. These dips are possibly of the right magnitude, as they approximate the range of dips measured in the overridden block near the trace of the Devil Ridge thrust farther southeast.

The fault found in both wells is presumably combined Devil Ridge and Red Hills thrusts. The fault lies along or near the contact between the rocks of Washita age and of Late Cretaceous age (probably equivalent to the Eagle Ford Formation) in the Thaxton well and is in the upper part of the probably Eagle Ford equivalent at the Briggs well. Nearby in the northern Quitman Mountains, where traces of the three major faults seem to converge, the Devil Ridge is the only fault known to have strata of Late

[6] The Patillo and Welch Briggs 1 was drilled to a depth of 1,135 feet at a location about 600 feet due north of the Krupp Briggs 1 well. The Patillo well crossed the thrust at an altitude between 3,372 and 3,302 feet and passed from the Briggs Formation into the Eagle Ford Formation. Many gaps in the log impair its usefulness.

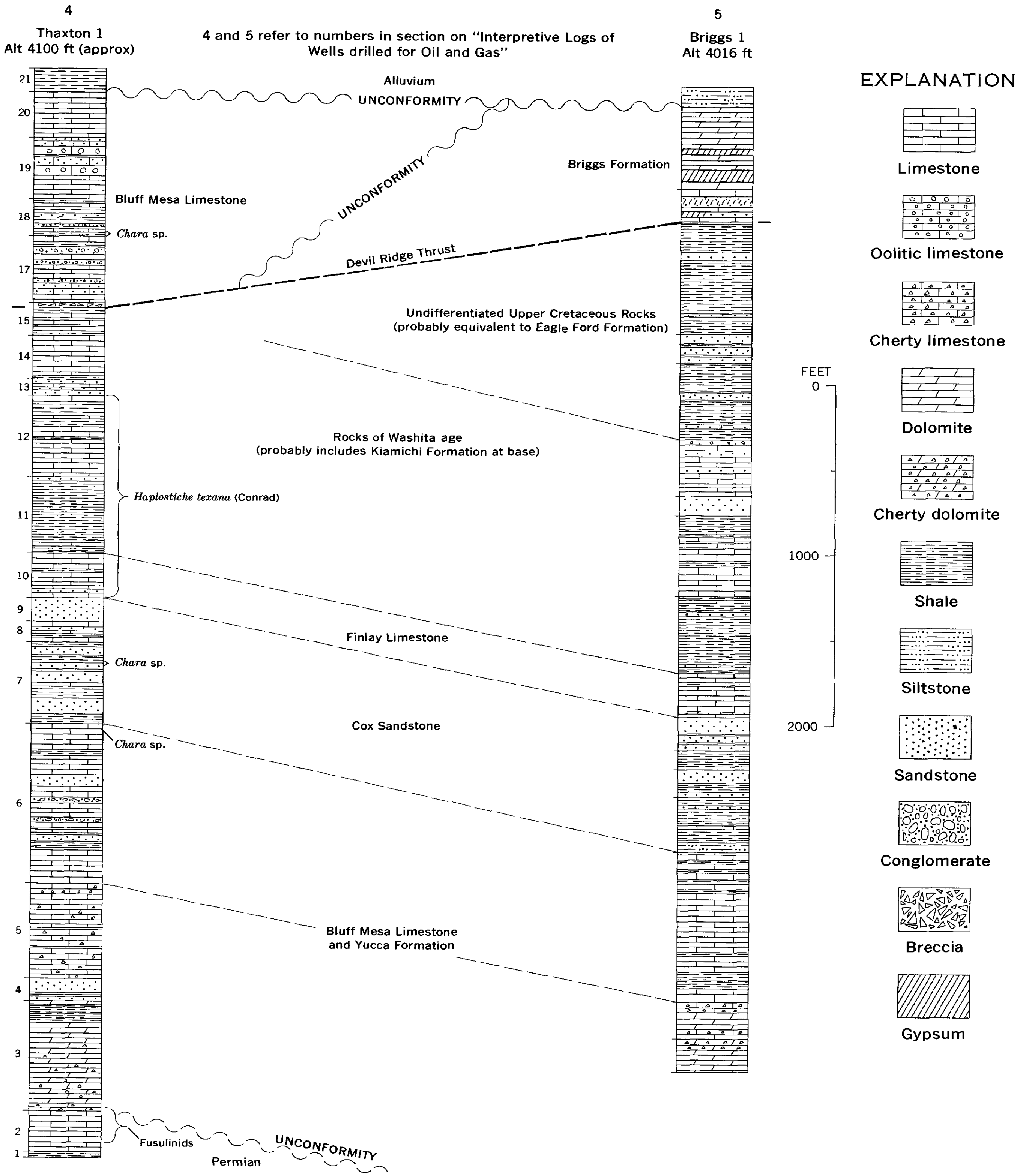

FIGURE 52.—Interpretive logs of wells drilled by Haymon Krupp Oil and Land Co.

Cretaceous and Washita ages along its footwall. The footwalls of the other two major thrust faults are almost certainly in older rocks, presumably in the Cox Sandstone. The structural complexity in the Malone Mountains and at Campo Grande Mountain is more like that in the Red Hills thrust block to the east. The combination of stratigraphic throw and structural complexity suggests that the Devil Ridge and Red Hills thrusts join and continue northwestward from the Quitman Mountains as a single fault.

THE MALONE MOUNTAINS

The Cretaceous and older rocks are more strongly folded in the Malone Mountains than in most other parts of the Sierra Blanca area. Axes of the more persistent folds are sinuous but generally trend northwestward parallel to the trend of the range. In the broader, northwestern part of the mountains, most of the anticlines and synclines are open, and many are nearly symmetrical. Toward the narrow southeast end, the folds are sharper, more closely spaced, and are locally overturned toward the northeast.

Three major structural features are related to folding. The ridge along the northeast front coincides with a synclinorium and has as many as eight subsidiary folds in the evenly bedded Jurassic and Cretaceous rocks. The rocks in the hilly lowland south of this ridge are anticlinal in the southeast and anticlinorial in the northwest, where several sharp folds are arranged en echelon. Ridges along the southwest border are formed on a homocline dipping southwestward but have local dip reversals related to gentle flexures. Apparently this wrinkled homocline persists several miles southwest of the mountains, as indicated by the position and attitude of the Yucca Formation and the Bluff Mesa Limestone in outlying hills.

The faults of the Malone Mountains trend northward or northwestward about parallel to the general strike of the bedding and the fold axes. Two minor thrust faults, with heaves of 50 to 350 feet, break the inverted limbs of anticlines at opposite ends of the range. Normal faults are concentrated in the northwestern part of the mountains, where the more persistent ones have throws of as much as several hundred feet.

At least three episodes of movement are recorded by the faults. The thrusts obviously formed during the later stages of folding. The normal faults are evidently younger because locally they dislocate the axes of the folds. Although most of the normal faults are older than the surrounding alluvial fill of the Hueco Bolson, one small fault along the southwest edge of the mountains drops older basin fill against rocks of Cretaceous age.

The spectacular folds of the Malone Mountains are probably no more than incidental effects of overthrusting. The log of the Briggs well shows that the Devil Ridge thrust is less than 1,000 feet below the mountains at their northwest end. Here the thrust separates two rock units that are among the weakest in the entire stratigraphic column, the gypsiferous sequence of the Briggs Formation and the shale of the undifferentiated Upper Cretaceous rocks. Corrugations in the overlying limestones of the Jurassic and Cretaceous Systems evidently reflect adjustments to flowage within the lubricating layers of gypsum below.

CAMPO GRANDE MOUNTAIN

On Campo Grande Mountain, a lone hill in the Hueco Bolson southwest of the Finlay Mountains, beds of Cox Sandstone and Finlay Limestone are folded into a syncline and an overturned anticline. Both fold axes trend northwestward and are slightly sinuous, like those in the Malone Mountains.

HUECO BOLSON

FAULTS IN THE BASIN DEPOSITS

By contrast with the folded and faulted Paleozoic and Mesozoic strata, the alluvial deposits of the Hueco Bolson are mainly flat and unbroken. They are cut by only a few high-angle normal faults, most of which cannot be traced for more than half a mile. The faults have displacements of as much as a few tens of feet. Although they form no definite pattern, they tend to parallel systems of older faults in the neighboring uplands.

The east end of one persistent normal fault crosses the valley of Campo Grande Arroyo directly to the south of Campo Grande Mountain, where it strikes N. 50° W. and dips 65°–85° S. This fault displaces both the younger and the older alluvial deposits of the bolson but does not extend through the overlying Madden Gravel (fig. 53). Sandy beds adjacent to the faults are firmly cemented by calcium carbonate; they therefore weather in relief as a low wall of sandstone. On the east slopes of the arroyo, the fault has a throw of 12 to 15 feet. This exposure must be near the southeast limit of the fault, as no evidence of it was found along Diablo Arroyo a mile to the southeast. Northwest of Campo Grande Mountain, the trace of the fault is marked by a resequent fault-line scarp 20 to 40 feet high which extends into the adjacent Fort Hancock quadrangle at least 15 miles.

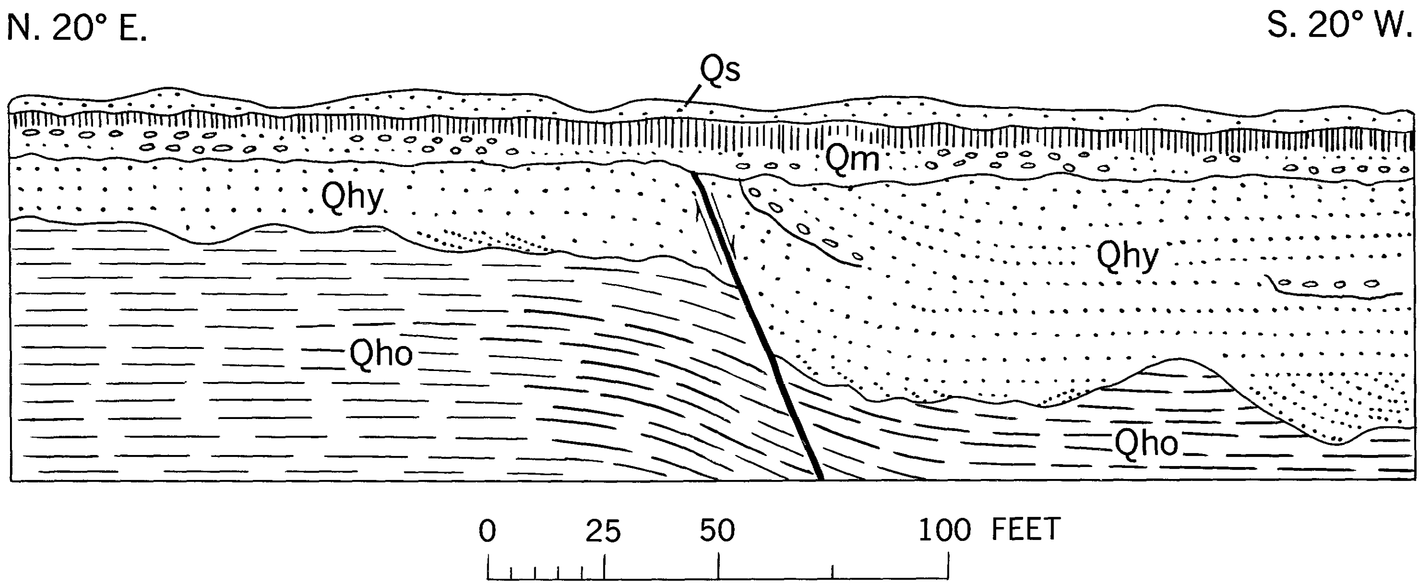

FIGURE 53.—Structural diagram of normal fault in alluvial deposits, 600 yards southwest of Campo Grande Mountain. Shown are sand and gravel of the younger basin deposits (Qhy) displaced downward against clayey beds of the older basin deposits (Qho). The fault is truncated by an erosional surface at the base of the Madden Gravel (Qm); caliche at top of gravel shown by vertical lines. Qs is windblown sand.

The height of the escarpment in the Fort Hancock quadrangle indicates that the throw probably amounts to several tens of feet.

About a mile west of Madden Arroyo, a vertical fault trending northeastward displaces the caliche of the Madden Gravel about 6 feet. An eastward-trending fault of similar magnitude breaks the same bed of caliche south of the old road to Finlay, near the northwest corner of the Fort Quitman quadrangle.

Perhaps the faults in the bolson reflect renewed movement along fractures in the underlying bedrock. If so, this movement occurred in at least two episodes: one before the deposition of the Madden Gravel and one after. There is no evidence of faulting in any gravels younger than Madden.

FOLDED OLDER BASIN DEPOSITS

Older basin deposits are folded in a northeast-trending belt exposed along two arroyos southwest of the northern part of the Quitman Mountains (pl. 7). In most places individual beds cannot be traced more than a few feet along the arroyo walls, but dips as steep as 45° are visible. In the southwestern exposures, the beds strike generally northwestward to north-northwestward; in the northeastern exposures, they strike north-northeastward. Small overturned folds and small thrust faults (fig. 54) in the older basin deposits are exposed along a cut bank about 1¾ miles southeast of Fort Quitman.

The folding of the older basin deposits probably did not result from mass movements attending slumping, gliding, or collapse, as the deformed belt is no more favorably located for such movement than are other areas of nondeformed basin deposits. Gypsum in outcrops near the deformed belt is evenly bedded in layers unaffected by solution, and no deformed beds are associated with it.

The northeastward trend of the belt of deformed beds is normal to the structural grain of the Sierra Blanca area, but deformation of these beds may re-

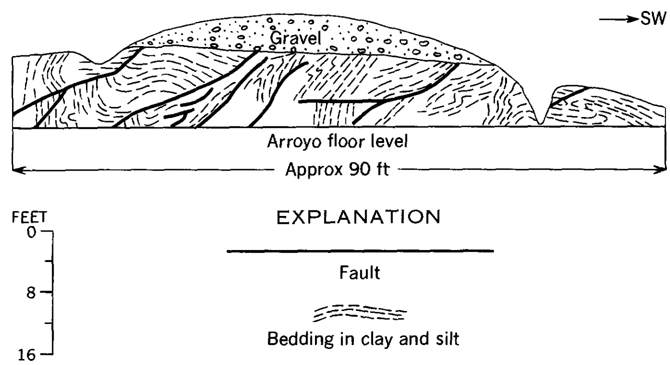

FIGURE 54.—Deformed clayey and silty older basin deposits on south wall of an arroyo about 1¾ miles southeast of Fort Quitman. Faults and folds are truncated by an erosional surface at the base of the Balluco Gravel.

cord renewed movement along a fault zone that may have crossed the Quitman Mountains at the position of the south end of the Quitman pluton and extended to the broad brecciated zone just west of Bluff Mesa (fig. 57).

QUITMAN CANYON

No deformed beds were observed in Quitman Canyon, and nothing else was found to suggest that the valley is controlled by any structural feature other than the strike of the folded bedrock. A well drilled just south of the mapped area, about midway between the Quitman Mountains and the main arroyo, penetrated 250 feet of alluvium on top of bedrock.

EARTHQUAKE CRACKS IN QUITMAN CANYON

Open cracks that are said to have formed during the Valentine, Tex., earthquake of 1931 cross the alluvium near the center of Quitman Canyon at the south edge of the mapped area. These cracks are about 75 miles west of the epicenter of the earthquake, in an area subjected to a disturbance of intensity 7 on the Rossi-Forel scale (Sellards, 1932, p. 116).

The cracks have two chief trends (fig. 55). The longest and most conspicuous ones trend N. 10°–25° W., and a shorter set trends N. 65°–80° E. and forms connections between the longer ones. In 1949, 17 years after the Valentine earthquake, many of the cracks were still partly open to depths as great as 7 feet and widths of 5 inches to 3 feet. The major northwestward-trending cracks cut across the drainage, and at the time of our visit several of the deeper holes contained water from recent rains. Mesquite and greasewood grow more luxuriantly near the cracks than on the nearby flats.

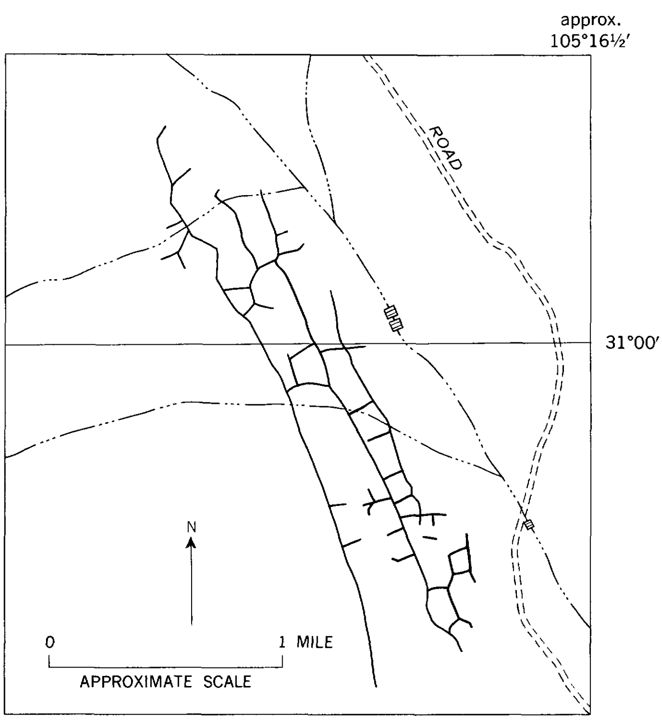

FIGURE 55.—Earthquake cracks in alluvium in Quitman Canyon at the south edge of the Sierra Blanca area. Map traced from aerial photograph taken February 27, 1941, about 9½ years after the earthquake.

EAGLE FLAT

Eagle Flat is an intermontane basin filled to unknown depths with unconsolidated sediments. A well east of the town of Sierra Blanca was drilled 1,000 feet in "alluvium" (Winslow and Kister, 1956, p. 90–91), and the Southern Pacific Lines well at Hot Wells, about 10 miles east of the mapped area, was drilled more than 1,000 feet in unconsolidated deposits (Baker, 1927, p. 40). Largely on physiographic evidence, Eagle Flat has been interpreted as a tectonic basin lowered by faulting (King and Flawn, 1953, p. 16 and p. 114; Smith, 1940, p. 633–634). On the tectonic diagram (pl. 7) we do not show faults along the borders, although the basin may be genetically related to some of the faults near the west end of the flat.

THE HILLSIDE FAULT AND THE TEXAS LINEAMENT

The high-angle fault between Texan Mountain and Flat Mesa has been interpreted by Moody and Hill (1956, p. 1223–1224, fig. 12) as a left-lateral wrench fault connecting with the Hillside fault of the Carrizo Mountains some 24 miles to the southeast (King and Knight, 1944; King and Flawn, 1953, p. 112, pl. 1) (fig. 56, this report). The two faults have similar strikes and trend into Eagle Flat, but strict projections of their strikes would not connect them; the Hillside fault would extend near the north side of Eagle Flat, and the fault along the north side of Texan Mountain would extend nearer the south side. They may, however, be parts of a broader zone. Both faults are downthrown northward, whereas most of the other high-angle faults of northwesterly trend in this region are downthrown southward. If Eagle Flat is in fact a structural basin, these faults are favorably situated to form parts of its boundaries, but displacement on the Hillside fault is in the wrong direction. Eagle Flat presumably is downthrown toward the south relative to the Diablo Plateau, whereas the Hillside fault is downthrown to the north and has repeatedly had downthrow to the north (King and Flawn, 1953, p. 117).

We find no direct evidence of strike-slip movement along these faults. King and Flawn (1953, p. 117–

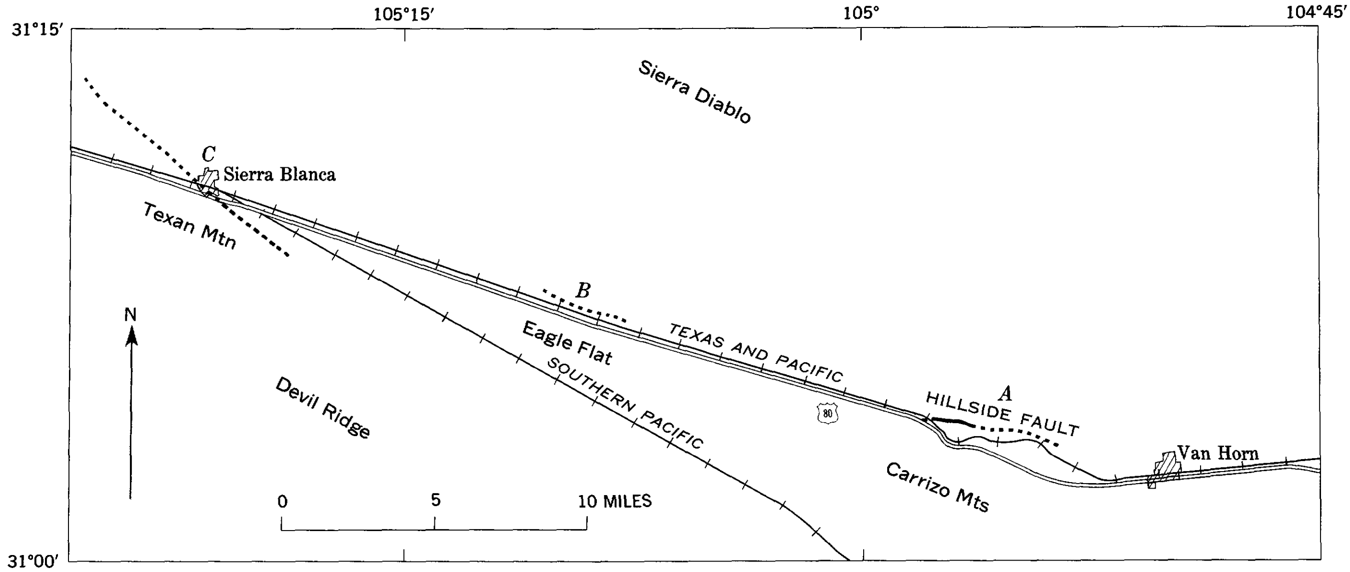

FIGURE 56.—Position of faults relative to Eagle Flat. Fault concealed where line is dotted. Hillside fault (*A*) and fault north of Texan Mountain (*C*) are downthrown to the north; fault *B* is downthrown to the south. Faults *A* and *B* after King and Flawn (1953, pls. 1 and 3).

119) reported small strike-slip movements on the Grapevine and other faults in Precambrian rocks and considered all these movements to be probably of Precambrian age. They noted that the northwestward grain of this region was established in Precambrian time, and movement along this established pattern was renewed at later times and under different stresses, so that an interpretation of a mechanism of faulting based on this pattern must be most uncertain. Although the zone of faulting can be extended northwestward into the Hueco Bolson, any extension eastward from the Carrizo Mountains area is difficult because no similar structural border zone has been found in that direction. This abrupt ending makes it doubtful that large strike-slip movement occurred along the zone in this region.

Moody and Hill (1956, p. 1223, 1229, and fig. 11) further interpreted their extended Hillside fault to be no more than a short segment within the Texas lineament of Hill (Ransome, 1915, p. 295, 358, 369). The Texas lineament is a transcontinental zone of fracture supposed to extend from Texas across southern New Mexico into Arizona and perhaps into southern California and beyond. That Ransome (1915, p. 295) was not convinced of the zone's reality is indicated by his statement that "The entire, rather vaguely defined and perhaps in part imaginary, zone from the Pacific to the Gulf of Mexico may be called the 'Texas lineament.' "

We have reviewed the evidence for and against the Texas lineament elsewhere (Albritton and Smith, 1957) and have concluded that, while the existence of the lineament has not been established, the strongest evidence in its support comes from the Sierra Blanca area and the country directly to the east and west. Many lines of evidence indicate that since Permian time, at least, geologic histories have differed on the two sides of the belt along Eagle Flat and westward between the Quitman Mountains and Sierra Blanca Peak. Also, the north edge of thrusting in the Sierra Madre Oriental lies in this belt and was probably controlled by thinning of Mesozoic strata at the north margin of the Mexican geosyncline. That the belt has long been a boundary between unlike geologic provinces is hardly subject to doubt, but whether this border is part of a transcontinental zone of fracture is not yet established.

RELATION OF INTRUSIVE IGNEOUS BODIES TO PRE-INTRUSIVE STRUCTURES

The forms of the intrusive bodies in the Sierra Blanca area differ according to their structural environment. The large intrusive bodies, but obviously not the dikes, in the structural platform north of the area of thrusts are mainly concordant, whereas those in the more complexly deformed beds and geosynclinal belt to the south are discordant. The size and shape of the Quitman pluton may have been effected in some part by a structure older than the possible caldera and ring dike.

The southern part of the ring dike has an unusually straight northeastward trend for about 2½ miles (fig. 1). Southwestward and on the same line is the belt of deformed basin deposits. To the northeast is the broad brecciated zone at the west end of Bluff Mesa. A line connecting these features (fig. 57) may mark a transverse zone of structural weakness which influenced the formation of the south end of the ring fracture. Movement must have been reactivated along part of this zone after deposition of the older basin fill to cause the deformation of these deposits in a local area, but no indications of any pronounced post-intrusive fault movement were found along the dike.

STRUCTURAL HISTORY

The structural history of the Sierra Blanca area before deposition of the Leonard Series of Permian age is unknown because no rocks older than the Leonard are exposed. Probably, though, the history was similar to that in the Van Horn area adjacent on the east in which the rocks were deformed during Precambrian time and also probably during pre-Permian late Paleozoic time (King and Flawn, 1953).

In the report area the recorded history began during Leonard time. Repeated uplift along the edge of the Diablo Platform is suggested by the thick accumulations of limestone conglomerate in the Leonard Series of the Finlay Mountains adjacent to the platform. At some time during late Paleozoic, Triassic, or Jurassic time, the Permian strata were gently

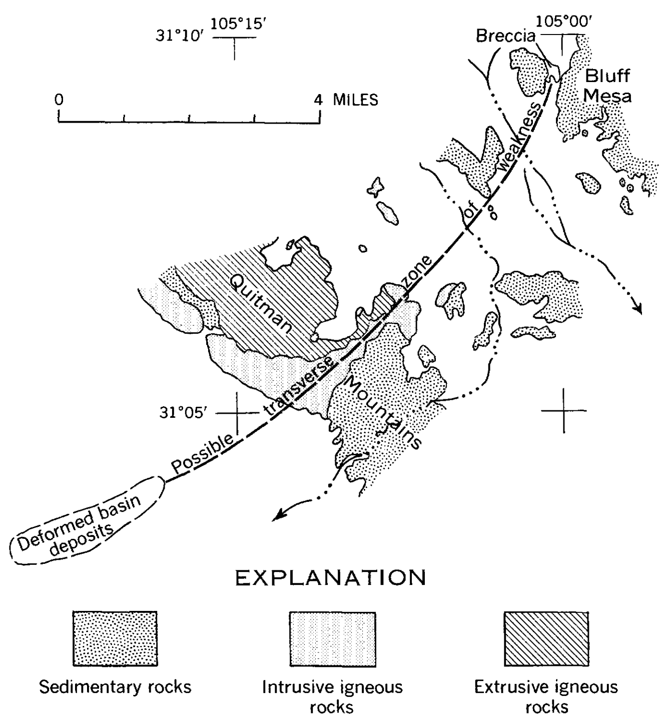

FIGURE 57.—Alinement of deformed basin deposits, south end of Quitman intrusive igneous body, and large breccia zone at west side of Bluff Mesa. These alined features may be along a transverse zone of structural weakness.

flexed, as indicated by the angular discordance at the base of the Mesozoic sequence. During Late Jurassic and Early Cretaceous, an area roughly along the edge of the present Diablo Plateau was again subjected to intermittent uplift, while a geosynclinal belt to the south subsided, as indicated by the abundance of limestone conglomerate in parts of the Malone, Etholen, Yucca, and Campagrande Formations. Thereafter the subsidence became more general, and the Mexican sea spread beyond the confines of the geosynclinal trough and over the platform to the north.

The major deformation that produced the folds, the thrust faults, and many of the normal faults occurred during Late Cretaceous or early Tertiary time and thus was probably a part of the Laramide orogeny of western North America. The youngest strata deformed in the Sierra Blanca area during this orogeny are the undifferentiated Upper Cretaceous rocks, which are probably equivalent to the Eagle Ford Formation; but still younger Late Cretaceous rocks, probably equivalent to the Taylor Marl, are reported in the same belt of deformation in the Eagle Mountains to the southeast (Baker, 1927, p. 31). The age of these deformed rocks indicates that the diastrophism was no older than late Late Cretaceous, than the Senonian Stage of Europe. No known evidence from the region affords a date for the end of the major deformation. In the report area the folded Cretaceous and older beds were uplifted and eroded extensively prior to eruption of the Square Peak Volcanics, which on scanty evidence are dated as early Tertiary, possibly Eocene or Oligocene.

Two intervals of thrust faulting are recorded in Trans-Pecos Texas: (1) the main first interval represented by the thrusts in the Sierra Blanca area and by similar thrusts in adjoining areas and (2) the second interval represented by thrusts that followed the eruption of some of the lavas (Baker, 1927, p. 37; 1934, p. 150, 189–190; King, 1935, p. 248-249; Gillerman, 1953, p. 51). No record of the second interval was found in the area of the present report.

The only conspicuous folds that formed after the main orogeny are those that accompanied emplacement of the large intrusive igneous bodies, such as the domes of the Finlay Mountains and Triple Hill. Although these intrusive bodies and associated structures cannot be dated on any direct evidence, they are presumably early Tertiary on the basis that all the large intrusives are about the same age and that one of them, the Quitman pluton, is comagmatic with the Square Peak Volcanics of probable early Tertiary age.

Some of the normal faulting occurred after the main orogeny, but no faulting is established as being younger than the Gills Gravel, the next to youngest of the Quaternary gravels on the broad erosional surfaces in the Hueco Bolson. This post-Laramide faulting evidently occurred at different times rather than during a single episode, and movement probably recurred along some older faults or fault zones. In the Malone Mountains, for example, most of the normal faults are older than the deposits of the Hueco Bolson, but one displaces older basin deposits (probably Pliocene) against Cretaceous rocks; these faults trend generally parallel to the strike of the Mesozoic beds but dislocate the axes of some of the folds. In the Finlay Mountains, the normal faults are mostly older than the dikes, but some are younger than the sills which must be about the same age as the dikes. In the Hueco Bolson at least two episodes of faulting are indicated: one before deposition of the Quaternary Madden Gravel, and one later; the Quaternary Gills Gravel and younger deposits are not disturbed. The basin deposits also were folded and thrust on a very small scale southwest of the Quitman Mountains, but here they are truncated by the erosion surface beneath the Balluco Gravel and so the deformation at least antedates that gravel; this deformation probably resulted from recurring movement along an older fault zone.

GEOMORPHOLOGY

Processes at work on the landscape of the Guadalupe Mountains nearby to the northeast, presented in an earlier paper (King, 1948, p. 126–138), apply in the main to the Sierra Blanca area, so do not need repetition. The following discussion is limited to such additional features as have special application to our own area.

WEATHERING

The rocks of the Sierra Blanca area weather differently depending on their composition, structure, and topographic situation. Limestone, dolomite, and gypsum are slowly dissolved by rainwater, although the carbonates and sulfates taken into solution are commonly redeposited near the surface as the water evaporates. Calcareous sandstone disintegrates as water moves through the voids and dissolves the carbonate cement. The monzonite and other relatively coarse textured igneous rocks of the Quitman Mountains disintegrate to a rubble of crystals and rock fragments, largely as the feldspars swell by alteration to clay minerals.

Root wedging is the most effective process of mechanical weathering in the stratified rocks of the mountains. Joints occur in all the harder rocks, and plants have an amazing capacity for growing in the tiniest crevices. Expansion of the growing roots is particularly effective in loosening and detaching joint blocks of quartzite, rhyolite and porphyritic lava, which of all the varieties of rocks in the area are perhaps the last susceptible to chemical weathering.

Other kinds of mechanical weathering are relatively insignificant. Frost wedging during some past epoch of colder and wetter climate may account for accumulations of sliderock along the upper slopes of Sierra Blanca peak. Spalling of rock by brush fires is an unlikely agent of disintegration at present but may have been more important before ranching operations reduced the cover of grass and scrub. In the northern part of the Quitman Mountains, one occasionally finds large boulders split in two, as though broken by a blow from above. These have probably been split along incipient joints or perhaps rarely by lightning rather than by differential expansion attending diurnal changes of temperature, as suggested by Streeruwitz (1893, p. 143–145). The weakly consolidated alluvial and colluvial deposits of valleys and basins are the refuge of burrowing animals, the prairie dog in particular, which continually loosen and turn material near the surface.

WEATHERING OF LIMESTONE AND DOLOMITE

Rainwater falling on crystalline limestone and dolomite slowly corrodes the rock and forms cavities, facets, and small channels. Where the rock is pisolitic or conglomeratic, details of sculpture are usually too intricate and irregular for analysis. Where the rock is evenly bedded and fine textured, divided into blocks by joints, and exposed on dip slopes, effects of corrosion differ systematically with the inclination of the slope. Tinajitas—shallow, subcircular, steep-walled solution cavities (Udden, 1925; King, 1927)—are characteristic of surfaces inclined at 3° or less. Smooth facets are corroded on joint blocks whose original angle of inclination is about 3°–6°. On steeper surfaces the rills of water etch furrows separated by serrate ridges.

These three forms of solution sculpture occur only where the joint blocks are affected by the water that falls on them and intervening cracks along joints provide gutters for the collection and discharge of water that spills from the tops of the blocks; Udden (1925, p. 7) attributed much of the solution of the rock to the action of microscopic algae. Tinajitas are thus etched on flat slopes where water can be ponded and flushed by overflow. Facets form where slopes are sufficiently steep to prevent ponding but gentle enough to allow water to flow as thin sheets. Furrows form where rills gather on steeper slopes.

All these effects of solution are well formed on the Finlay Limestone and Campagrande Formation, especially along Devil Ridge, Flat Mesa, in the western Finlay Mountains, and on the Diablo Plateau (Smith and Albritton, 1941).

The upper surfaces of cobbles and boulders strewn over the terraces and erosion surfaces are also pitted and faceted. All the solution-faceted shapes described by Bryan (1929) occur along with others more elaborate. Remarkably intricate relief is formed by solution of the dense limestone of the Yucca Formation; its cobbles are commonly pitted with craterlets bounded by jagged crests and with tiny channels that run down the sides, but the bottoms of solution-faceted stones preserve their original shapes. Undercoatings of secondary carbonate are common, derived from precipitation of material dissolved from the top.

The nature of the caliche on the gravel-capped erosion surfaces in the Hueco Bolson supports the hypothesis that the caliche is derived from limestone gravel by solution and redeposition of calcium carbonate (Bretz and Horberg, 1949). Here, as well as in southeastern New Mexico, cupped pebbles and residual inclusions of insoluble materials occur in the caliche. Additional support for the hypothesis is found in the areal distribution of the caliche. In the southwest quarter of the report area, for example, the caliche is mostly confined to an area west of a line joining Hilltop Cafe and Quitman School. The streams to the west of this line head in uplands where limestone is abundant, and those to the east drain mountains made mostly of igneous rock.

The caliche is ordinarily thicker and more compact on the older surfaces than on the younger. On the Madden surface, it is chalky and contains scattered residual fragments of andesite porphyry, quartzitic sandstone, and other relatively insoluble materials. On younger surfaces the caliche contains more cupped pebbles of limestone and commonly rests on a substratum of limestone gravel.

WEATHERING OF CALCAREOUS SANDSTONE

Wherever sandstone in the Cox Sandstone is cemented with calcite, its outcrops show corrosional features similar to those on limestone. Tinajitas are as common on flattish surfaces of the sandstone as on the limestone; they evidently form wherever water is ponded and dissolves the cement. On sandstone they are further deepened by release of grains of sand which are later blown away by the wind. At an Indian campsite along the base of the Diablo Plateau, about 10 miles northwest of the Wilkie Ranch house, mortar holes drilled in the tinajitas have been enlarged several inches as a result of disintegration since the site was occupied.

Many of the sandstone boulders that litter the steeper slopes of cuestas in the Finlay Mountains are protected from weathering by an iron-enriched skin of desert varnish, which is now being destroyed. Destruction ordinarily begins around the bases of the blocks, which are exposed to rainwash. Accelerated disintegration along the bases produces natural shelters, many of which have been occupied by Indians.

The profusion of these huge angular boulders suggests that the caprocks are disintegrating fairly rapidly by the detachment of blocks that then creep down slopes of shale and sandstone. That such movement has gone on at some time during the past is without doubt, but archeological evidence indicates that many of the blocks have maintained their present positions for the last several centuries.

At the Wilkie Ranch house, for example, a cliffy sandstone face on the steeper side of a cuesta is covered with drawings pecked into the rock by the Indians. Similar petroglyphs were found on 60 of the large blocks that lie on a 20° slope below the cliff. Many of the drawings are of men and animals, all of which are in upright position. Obviously, there has been no detachment of blocks from the cliff since the petroglyphs were made, nor have the blocks on the slope rolled or toppled. Middens along the downslope edges of several of the blocks have not been overridden by the sandstone blocks against which they abut. Pottery from the middens has been dated as A.D. 1200–1300 (Campbell and others, 1941; Howard, 1941; Osburn, 1941; Walker and Trexler, 1941). If the pottery and the petroglyphs are contemporaneous, as they almost certainly are, the cliff and the boulders have maintained their present attitudes for the past 600 or 700 years.

WEATHERING OF GYPSUM

In the Malone Mountains, alternate wetting and drying of gypsum causes the superficial layers to recrystallize as coarse selenite in crusts several inches thick. As the crusts are more friable than the parent material, they are stripped from slopes during downpours and broken into platy fragments. The plates disintegrate readily as they are moved, but if the transport is no more than a few tens of feet, many of the plates remain intact. They are washed together in gullies where they become loosely cemented on drying and form an extremely porous breccia. Subsequent erosion leaves residual pillars of this unusual rock. Ultimately the crusts are reduced to sand-sized and pebble-sized aggregates that are swept down the arroyos toward the Rio Grande.

Although gypsum might be expected to waste mostly by solution, here it is being eroded mechanically in large part and moved down the arroyos as detrital material.

MASS WASTING

Movement of large masses of rock primarily in response to gravity does not seem to be a common process of wasting now but has been important in the past.

Slumping of alluvial deposits along the steep sides of arroyos commonly takes place after heavy rains. The process is especially active along undercut banks in clayey alluvium, which expands and sloughs off when wet.

Large landslide blocks of the kind sometimes called "toreva blocks" occur along the base of slopes leading up to the Diablo Plateau. The largest, along the north side of Prince Albert Canyon, have been studied by Trace (1942). Here the blocks are as much as 1,700 feet long and 300 feet across and are elongated parallel to the margin of the plateau. The strata in the blocks are of the Cox Sandstone, although some blocks probably were once covered by the Finlay Limestone. The displaced beds dip toward the plateau at angles of 15°–30° and were rotated backward along curved fractures in the process of sliding over clayey beds in the lower part of the Cox Sandstone. The blocks are dissected by gullies along the strike of the weaker strata, and the tops are truncated by erosional surfaces that probably correlate with the surface on which the Madden Gravel rests.

Lower slopes of mesas and cuestas capped by the thick layers of Cox Sandstone commonly are covered by large joint blocks slumped from the caprock. Many of these blocks are 10–25 feet across. In places the blocks cover as much as 80 percent of the slopes.

Trains of slide rock fill the heads of ravines on Sierra Blanca Peak. These accumulations are several hundred yards long, probably as much as 20 feet thick, and made of joint blocks of the fine-textured rhyolitic rock that forms the greater part of the mountain. Although the slide rock appears unstable, the slabs are actually wedged together so tightly that they do not slide or roll when they are walked upon. Little slide rock is probably being added to the trains, and they may have formed during a colder and moister climate, when frost wedging was a more active process of disintegration.

EROSIONAL SURFACES OF THE BASINS

Erosion surfaces of the Hueco Bolson and outlying areas are covered by caps of gravel or caliche. Exposures along arroyos clearly show that the caps truncate the bedding in the underlying bolson deposits, although the angular discordance is generally slight. The surfaces of truncation are fairly even in most exposures, but locally they have a few inches to a few feet of relief. They are largely cut across clay, sand, and conglomerate of the basin deposits but extend onto older bedrock along the mountain flanks.

All five of the gravel-capped surfaces mapped in the Hueco Bolson were formed by the same process but at different times. Possibly they represent times of stabilization in the local base level, which in this area is the channel of the Rio Grande.

Broad fan-shaped surfaces capped with gravel border the west side of the northern part of the Quitman Mountains and the Sierra Blanca peaks. After viewing some of these from a distance, Johnson (1932, p. 415–416) sugested that they are "rock fans." An erosional surface that probably satisfies Johnson's definition of rock fan is trenched by a gully on the north side of Round Top. Below a sheet of gravel about 20 feet thick the shale, marl, and sandstone of Washita age are exposed near the mountain. The upper and lower surfaces of the gravel are approximately parallel and dip 15° to the north, whereas the underlying beds of Washita age dip 20° to the southwest. The gravel thins upslope and ends near the rhyolitic core of the mountain. Bedrock below the gravel is not exposed far enough away from the mountain, however, to permit conjecture on the shape of the bedrock surface toward the toe of the fan.

Slopes leading up to the Quitman Mountains from the west have the configuration of alluvial fans but are composite pediments capped with gravel of at least three different ages. The pediments are partly cut on the fanglomerate of the older basin deposits and partly on the sandy or clayey facies. Over the apices of these "fans" and within a few hundred yards of the mountain front, intermittent streams that head in the mountains are spreading a veneer of alluvium. At the same time the margins are being dissected by streams that head on the bolson.

This interplay of erosion and deposition in the modeling of land forms is well demonstrated below Black Canyon off the southwest side of the Quitman Mountains. The master stream here deposits alluvium near the edge of the mountains where its carrying capacity is diminished by a decrease in gradient. Other streams heading below the mountain front intermittently transport gravel down channels choked with coarse debris. Still farther downslope, steep-headed gullies, some as much as 40 feet deep, expose the basin deposits below the gravel. Intermittent streams cutting these gullies work headward in the softer basin deposits and undermine the gravel cap. In most places, 5 to 20 feet of gravel overlies the basin deposits along a fairly even surface that apparently truncates the older alluvium. Simultaneous deposition and erosion in similar situations has been described by Rich (1935) and Hunt (1953, p. 189–192).

We were not able to identify any single process as being uniquely responsible for development of the pediments. Sheet wash, rill wash, and lateral planation by streams are all active in the Sierra Blanca area. During very heavy rainfall, sheets of water a few inches deep and hundreds of feet wide may flow across the broader pediments. The moving water that precedes the sheets flows in rills, and as the volume of water decreases the rills reappear. All this flowing water moves clay and sand and some larger fragments, but we have not observed a flood competent to remove an entire capping of pediment gravel and erode the bedrock below. Water flows along rills with almost every rain and consequently rill flow is much more common than sheet flow.

The widths of the arroyo flood plains indicate that lateral planation is effective under present conditions. During most rains the flowing water remains in the channels of the arroyos, but during the heavier floods, the banks are eroded, and the channels shift position on the arroyo bottom. In some areas mapped as flood-plain deposits there is actually no main channel; the water moves in a plexus of small channels more as a series of rills than as a single stream. Intermittent erosion in such areas eventually leaves deposits of older gravel standing as islands. In the Hueco Bolson the contacts between older and younger capping gravels in many places have sweeping curves similar in shape to curved margins along the present flood plains, a fact which suggests that lateral planation was responsible in part at least for cutting the surfaces beneath the gravels.

EL PASO VALLEY

Remnants of two low cut-and-fill gravel-capped terraces remain on the ends of spurs bordering upon the El Paso Valley. Trends of cut banks indicate that the terraces were formed chiefly by the Rio Grande, although equivalent terraces were formed along some of the tributary streams. About 1½ miles east of Quitman Cemetery, the upper part of the higher tributary terrace has been cut off by an arroyo.

Small alluvial fans have been deposited along the edges of the Rio Grande flood plain at the mouths of the tributary arroyos. For about half the length of the flood plain, these fans coalesce to form a continuous blanket of clay, silt, sand, and gravel that has an average width of slightly less than half a mile. In essence, the history of the El Paso Valley has been one in which the Rio Grande has been widening its flood plain while its tributaries have been hemming it between fans. The alinement of the ends of gravel-capped spurs between arroyos opening up on the flood plain indicates that these spur ends were eroded by the Rio Grande. The higher terraces were likewise trimmed by sideward sweeps of the river, although in places the fans built at arroyo mouths have separated the terrace remnants from the present Rio Grande flood plain.

RESOURCES

Ground water is a most important resource in the economy of the area. In general, the supply is adequate for domestic use and for the livestock. Materials for road construction and masonry are abundant beyond present needs. Several wells have been drilled for oil, but all have been dry.

Mineral deposits containing base metals, silver, and tungsten have been extensively prospected in the Quitman Mountains, but no appreciable quantities of metallic ores have been produced.

METALS

Metalliferous deposits have long been known to exist in the northern part of the Quitman Mountains. Deposits of iron, copper, lead, zinc, nickel, silver, uranium, and gold were described by Streeruwitz (1890, p. 221, 223–226; 1891, p. 691–697; 1893, p. 148–159) and later noted by Baker (1934). Numerous prospect pits have been dug into the hillsides along dikes and veins cutting the Quitman pluton and also in the nearby metamorphic rocks, but little prospecting has been done recently.

The "Bonanza fissure," on which the Bonanza mine is located in the northern part of the Quitman Mountains, has been much prospected and intermittently mined. It is a northeast-striking vein along a dike that cuts the Quitman pluton and is partly exposed for a distance of about 150 feet west of the alluvial cover. It has been explored from three shafts for about 400 feet along the strike. At the time of our visit the workings were largely flooded and were not accessible. At the surface the vein is 6 inches to 2 feet wide and contains galena and sphalerite intergrown with quartz and carbonate minerals. Some uranium is also present, as shown by chemical analyses. Two pieces of quartzose sulfide ore contained 0.073 and 0.021 percent U_3O_8; vein rock with negligible amounts of sulfide minerals contained 0.001–0.015 percent U_3O_8; and two samples of altered wall rock contained 0.076 and 0.046 percent U_3O_8 (analysts: G. W. Boyes and J. H. Wahlberg, U.S. Geol. Survey, 1951). The wallrock is altered through widths of 2 to 8 inches on either side of the vein.

Secondary copper minerals occur at nearly all the prospects in the northern part of the Quitman Mountains and particularly at those on the west side near Silver King Canyon. Small amounts of chalcopyrite and wulfenite have also been reported. Iron and manganese oxide minerals coat the rocks at many of these prospects.

The tungesten-bearing mineral scheelite has been known since 1916 in recrystallized sugary limestone beds of the Torcer Formation where it has been metamorphosed on the west side of the Quitman pluton and west of a line projected along the Bonanza fissure (Udden, 1941). According to a report by J. F. McAllister (written commun., 1942), the scheelite is in isolated grains, coarse aggregates, and thin veinlets replacing the limestone. Rock discontinuously mineralized with tungsten was traced for about 700 feet along the contact zone. The principal minerals associated with the scheelite are specular hematite, garnet, epidote, tremolite, pyrite, quartz, calcite, and secondary copper minerals.

FLUORSPAR

Fluorspar has been prospected at one locality on the east slope of the Quitman Mountains about 3½ miles southwest of Bug Hill. A trench about 20 feet long in lavas of the Square Peak Volcanics exposes a fluorspar vein 4 inches to 2 feet wide that trends N. 65° E. and dips between 55° SE and vertical. The fluorite is clear, light green, or purple and forms discontinuous stringers that also contain siliceous material. Fragments of lava embedded with the fluorspar indicate that the vein follows a fracture zone, although no measurement of displacement could be made. Several shallow pits to the northeast along the trend of the vein have been largely filled and thus probably disclosed nothing worth mining.

Fluorspar has been mined from fissure veins associated with eastward-trending faults and subsidiary fractures in parts of Eagle Mountain southeast of the report area (Gillerman, 1953, p. 61).

CONSTRUCTION MATERIALS

Gravel and caliche from the deposits capping erosional surfaces of the Hueco Bolson have been taken in many places for road building. The composition differs from place to place although most of the gravel deposits contain limestone pebbles and cobbles.

Bedrock has been quarried, or large boulders have been taken from the surface near the edges of the mountains for construction work requiring larger rock fragments. Lava boulders from alluvial deposits near the mouth of Black Canyon and basalt from the volcanic neck south of U.S. Highway 80 have both been used as riprap along the Rio Grande channel. Riprap for controlling erosion of the arroyo banks at small bridges or along local road embankments is commonly obtained by collecting loose blocks of sandstone, quartzite, and limestone from nearby hillslopes.

Some houses and buildings in the area are constructed of local stone, especially the Cox Sandstone, which is easily quarried and cut into building blocks; loose blocks from the surface have also been used after reshaping.

CLAY

Clay from the older basin deposits is used as drilling mud. It is dug from open pits, the larger of which are about a mile southeast of Finlay. Their exact location is largely determined by considerations of convenience in extraction, hauling, and shipping. The mined product is pulverized in ball mills. Part of it is sacked and marketed as rotary clay, and the remainder is shipped to points where the clay is blended with bentonite. Extensive clay deposits, similar to those already developed, crop out along Arroyo Balluco and farther westward.

GYPSUM

Gypsum of the Briggs Formation has been quarried sporadically at the railway station of Gypsum, near the northwest end of the Malone Mountains. Much of the product has been shipped to El Paso for use in making plaster. The gypsum is naturally exposed in gullies and along hillslopes. On divides between gullies the gravel overburden is generally no more than a foot or so thick. Dolomite interbedded with the gypsum is mostly concentrated as lenses, the larger of which are removed as waste in the process of mining.

Gypsum crops out at many other places in the Malone Mountains, as shown by the geologic map. Except for the broad white flat a mile north of Hilltop Cafe, the exposures are relatively inaccessible and too far removed from loading and shipping facilities to be of commercial value at this time.

GROUND WATER

Nearly all the water used for domestic purposes in the Sierra Blanca area is derived from wells. Numerous small reservoirs or tanks constructed along arroyos provide supplementary water for livestock. Land along the flood plain of the Rio Grande is irrigated from the river, but this source is not available to the rest of the area.

The ground water is obtained from wells that range in depth from a few tens of feet to more than 1,000 feet. The water occurs both in bedrock and in the alluvial deposits of the basins and valleys.

Of the bedrock formations, the Cox Sandstone is the best aquifer. This formation yields its water most readily in the area north of the railway where the sandstone is coarest and most permeable. Shallow wells produce water from the Cox in the Finlay Mountains and probably also in the bolson to the west. Many wells on the Diablo Plateau derive their water from the Cox or from sandstone beds of similar lithology in the Finlay Limestone. Conditions favorable for artesian water in the Cox possibly exist in places along the southwesterly dipping flexure to the north of the Devil Ridge thrust. (See tectonic diagram, pl. 7.)

Ground water is also produced from wells in the alluvium of the basins. In the Hueco Bolson, a water well was drilled to a depth of 855 feet at Esperanza. According to a log supplied by the local storekeeper, the upper 500 feet of hole was in basin fill and the part below in "lime," "shale," and "anhydrite." This lower section could be either an evaporite facies of the older basin deposits or Permian bedrock, but the water probably comes from alluvial beds in the upper part of the well, as it is potable and not noticeably "gyppy."

Two wells near the west edge of Eagle Flat supply water for the town of Sierra Blanca. Both were drilled 1,000 feet in alluvial deposits of the intermontane basin; well 1 yields 40 gallons per minute, and well 2 yields 35 gallons per minute (Broadhurst, Sundstrom, and Weaver, 1951, p. 96–97).

The basin deposits in the Hueco Bolson derive water from a large drainage area, although much of the very fine grained basin fill probably is relatively impermeable. (See Sayre and Livingston, 1945.) Source areas for ground water in alluvial deposits of Quitman Canyon east of the Quitman Mountains and Eagle Flat are limited to the drainage from immediately surrounding hills.

Ground water is obtainable from alluvium at depths of 50 feet or less along many arroyos and washes. The quantity of water available varies with the size of the drainage basin, whereas the quality varies with the lithology of the drainage basin. Ground water along the lower reaches of Arroyo Balluco is thus relatively plentiful but contains much sulfate derived from gypsum in the Permian Briggs Formation upstream.

Only a small quantity of ground water issues at the surface as seeps or springs, which are most common along the south edge of the Diablo Plateau and in the Finlay Mountains.

OIL AND GAS

The Sierra Blanca area produces no oil or gas. Several dry holes have been drilled around structural domes in the northern part and on anticlinal structures in the south. Although these do not indicate a definite lack of oil and gas in the area as a whole, they have discouraged further exploration. Locations of exploratory wells, together with the deeper water wells for which logs are available, are shown on the geologic map (fig. 1). Interpretive logs are assembled in the next section of this report.

The shallow holes drilled in the Finlay Mountains and on the Diablo Plateau explored structurally high areas, some of which probably are related to uplifts above intrusive igneous rocks. The two deepest wells in the area—the Briggs 1 and Thaxton 1 of the Haymon Krupp Oil and Land Co.—were on anticlines. Although the Krupp wells were intended as tests of the rocks of Paleozoic age, both unexpectedly crossed thrust faults and passed into beds of Cretaceous age beneath; so, neither penetrated strata older than the Permian.

The possibility of finding oil and gas beneath the Devil Ridge thrust has not been discredited by the Krupp wells. The great thickness of the Cretaceous and older strata combined with the expectable variety of folded and faulted structures and the probable existence of stratigraphic traps are all favorable factors. The Krupp wells proved, however, that the visible structure and stratigraphy may be quite unlike the structure and stratigraphy below the thrust faults.

INTERPRETIVE LOGS OF WELLS DRILLED FOR OIL AND GAS IN THE SIERRA BLANCA AREA

In the following interpretive logs, the numbers in parentheses preceding the names of the wells refer to the well numbers on the geologic map (pl. 1).

(1) *Western States Oil Co., Lockhart, Roseborough, and Benton 1 Sidney Moore well*

Location: Gunsight Hills, block 71, sec. 16, T. 6, Texas and Pacific Railway Co. Survey. In center of section.
Elevation: 4,833 ft.
Total depth: 2,705 ft.

	Depth interval (feet)
Cretaceous System—Cox Sandstone:	
No samples	1–150
Limestone, gray, cream, tan, fine-textured; dolomitic in part, sandy in lower half; interbedded fine- to medium-grained calcareous sandstone and minor amounts of purple shale; contains oyster shells and oval smooth carapaces of ostracodes	150–200
Sandstone and shale, interbedded; sandstone is pinkish or yellowish gray, mostly medium grained but fine grained toward top and pebbly at certain horizons; carbonate cement; shale is purplish gray or mottled and sandy, and contains minor amounts of lignite	200–410
Shale, gray, reddish- or greenish-brown, gypsiferous, some sandy; contains *Chara* sp.	410–535
Cretaceous System—Campagrande Formation:	
Limestone, mostly gray or light brownish-gray (commonly brown, purple or pink toward base) fine-textured, argillaceous; a few dolomitic beds; small amounts of chert (as pebbles?) toward base; interbedded shale is mostly purplish gray or mottled toward base, slightly gypsiferous in lower part; contains echinoids and *Chara* sp	535–885
Unconformity.	
Permian System—Leonard(?) Series:	
Limestone, predominantly very dark brownish gray, containing minor amounts of hard black shale; *Schwagerina* sp. ranges from top to bottom; "worm tubes" common between 1,640 and 1,875 ft; other fossils include *Endothyra* sp., brachiopod spines, echinoid spines, crinoid stems, and ostrocodes	885–2, 050

(1) *Western States Oil Co., Lockhart, Roseborough, and Benton 1 Sidney Moore well*—Continued

	Depth interval (feet)
Permian System—Leonard(?) Series—Con.	
Limestone, cream, tan, or brown, cherty at certain horizons; contains fusulinids throughout, *Schwagerina* sp. at 2,090 and 2,180 ft	2, 050–2, 340
(Sill of igenous rock)	2, 340–2, 360
Limestone, cream, tan, brown, cherty; contains fusulinids and crinoid stems	2, 360–2, 560
Permian System—Wolfcamp Series:	
Limestone, predominantly dark-gray or brown; contains *Triticites* sp. at 2,560 and 2,630 ft; also brachiopods, ostracodes, and echinoderms	2, 560–2, 650
Clay, gray; contains limestone pebbles	2, 650–2, 670
No samples below 2,670 ft.	

Comments.—The total thickness of the Cox is about 562 feet—27 feet of section measured above the collar and the 535 feet drilled.

The thickness of 350 feet for the Campagrande is a maximum figure, even if the beds are assumed to be flat and the hole vertical. Because the contact is placed at the highest level of Permian fossils, the dark limestone is included in the Permian and the varicolored limestone and interbedded gypsiferous shale, in the Campagrande—a reasonable interpretation, but not necessarily correct.

Even though we have no way of judging the attitude of the Permian beds, the apparent thickness of the Leonard(?) is about the same as the measured thickness in the Finlay Mountains.

(2) *Western States Oil Co., Lockhart, Roseborough, and Benton; Gardner and Moseley 1 well*

Location: Block 18, sec. 12, Public School Land, 1,320 ft from north and west lines. On plateau north of the Finlay Mountains.
Elevation: 5,024 ft.
Total depth: 3,123 ft.

	Depth interval (feet)
Cretaceous System—Finlay Limestone:	
No samples	0–130
Cretaceous System—Cox Sandstone:	
Sandstone, gray and brown; interbedded with fine-textured limestone; numerous fragments of oyster shells	130–180
Limestone, brownish-gray, hard; contains oyster shells	180–220
Sandstone, limestone, and shale, interbedded; sandstone is gray to brown, fine to medium grained, calcareous; limestone is gray or brownish gray, commonly sandy, locally nodular; shale is gray or reddish brown and contains *Haplostiche texana* (Conrad)?, *Chara* sp. and some lignite	220–310

(2) *Western States Oil Co., Lockhart, Roseborough, and Benton; Gardner and Moseley 1 well*—Continued

	Depth interval (feet)
Cretaceous System—Cox Sandstone—Con.	
Sandstone, light-gray to yellowish-brown, fine- to medium-grained	310–370
Shale, varicolored—gray, purplish or reddish-brown; either highly gypsiferous or interbedded with gypsum; interbedded sandstone and earthy limestone; contains *Chara* sp., ostracodes, and small amounts of lignite	370–630
Cretaceous System—Campagrande Formation:	
Limestone, light brownish-gray, sandy (at certain horizons), interbedded with gray and maroon shale; contains miliolid foraminifers and *Chara* sp	630–803
No samples	803–847
Limestone, gray or brown, fossiliferous	847–884
Unconformity.	
Permian System:	
Limestone, brown, fine- to coarse-textured, cherty (at certain horizons), containing partings of black shale; contains *Endothyra* sp., fusulinids, and sponge spicules	884–1, 115
Unconformity.	
Silurian and Ordovician Systems—Fusselman(?) and Montoya Dolomites:	
Limestone, white to light-tan; contains small amounts of chert and dolomite	1, 115–1, 250
Limestone and shale, interbedded; limestone is white to cream and cherty; shale is white to greenish white, logged as bentonitic	1, 250–1, 300
Dolomite, white, cream, tan, mostly coarse-textured; contains small amounts of chert; some interbedded limestone	1, 300–1, 760
No samples	1, 760–1, 780
Ordovician System—El Paso Formation:	
Limestone, white, cream, tan, containing local partings of shale and small quantities of chert; contains brachiopods, gastropods, and pelecypods (not identified in log)	1, 780–2, 495
Limestone, as above, except contains abundant chert	2, 495–2, 555
Limestone, as above, except largely sandy, a few partings of shale, locally dolomitic and cherty	2, 555–2, 989
Ordovician and Cambrian Systems—Bliss(?) Sandstone:	
Sandstone, gray to greenish-gray fine- to coarse-grained, interbedded with limestone toward top and with greenish-gray shale toward base	2, 989–3, 115
No samples	3, 115–3, 123

Top of Precambrian estimated at 3,200 ft.

Comments.—Most of the Cretaceous strata are flat lying; so, the penetrated intervals are approximately true thicknesses. By this interpretation, the Cox is 500 feet thick and the Campagrande between 173 and 254 feet. There are at least three places where the base of the Campagrande can be placed; the lowest possible horizon is chosen in the belief that the thickness should be nearer 300 feet than 200 in this area.

(3) *Rio Grande Oil Co., Lockhart and Roseborough 1 well*

Location: East dome, Finlay Mountains, block 21, sec. 5, Public School Land, 1,320 ft from south and east lines.
Elevation: 4,858 ft.
Total depth: 1,786 ft.

	Depth interval (feet)
Cretaceous System—Campagrande Formation:	
No samples	0–330
Limestone and shale, interbedded; limestone is mostly light brown, fine textured, argillaceous toward top; shale is gray and reddish and greenish brown; chert (pebbles?) near base	330–496
Unconformity.	
Permian System—Leonard(?) Series:	
Limestone, dark grayish-brown to dark-brown, fine-textured, cherty (between 1,030 and 1,040 ft); contains "worm tubes," ostracodes, and fusulinids; *Schwagerina* sp. at 1,050 ft	496–1, 205
Permian System—Wolfcamp Series:	
Limestone, mostly very dark gray or brownish-gray, cherty; *Triticites* and *Pseudoschwagerina* at 1,210 ft, *Schwagerina* and *Pseudoschwagerina* at 1,270 ft	1, 205–1, 575
Intrusive contact:	
Igneous rock	1, 575–1, 681
No samples	1, 681–1, 786

Comments.—Because the sampling was very spotty, interpretation was difficult. The contact between the Campagrande and the Permian cannot be fixed with any degree of confidence. Conceivably the Campagrande extends down to 1,030 feet, where the first fusulinids were reported. A single fragment of *Chara* logged at 960–975 feet would seem to support this belief; but as the Campagrande can hardly be thicker than 650 feet in the Eastern Finlay Mountains and the dip no greater than 10° in the area drilled, the contact is placed at a higher level.

(4) *Thaxton 1 well of the Haymon Krupp Oil and Land Co.*

Location: Sec. 34, block 74, T. 6, Texas and Pacific Railway Co. Survey.
Elevation: 4,100 ft (approx).
Total depth: 6,402 ft.

	Depth interval (feet)
Alluvium:	
Clay, pink or buff. Sparsely sampled	0–135
Unconformity.	
Cretaceous System.—Upper Cretaceous:	
Limestone, brown, fine-textured	135–400
Limestone, dark-gray or brown; mostly sandy, pebbly, conglomeratic, or oolitic; fossiliferous between 450 and 475 ft; interbedded gray calcareous shale toward base	400–762
Shale, gray, reddish- or greenish-brown, commonly calcareous; interbedded dark-brown limestone, gray sandstone, and limestone conglomerate; *Chara* at 958–979 ft	762–979

(4) *Thaxton 1 well of the Haymon Krupp Oil and Land Co*—Con.

	Depth interval (feet)
Cretaceous System—Upper Cretaceous—Con.	
Limestone, brown, commonly sandy or pebbly; interbedded limestone conglomerate and varicolored shale, in part calcareous	979–1, 375
Fault zone.	
Breccia, fine-textured brown limestone containing numerous veins of coarse-grained white calcite; one crinoid stem at 1,375–1,383 ft	1, 375–1, 404
Cretaceous System—Rocks of Washita age:	
Limestone and shale, interbedded; limestone is brown, fine textured; shale is gray and greenish gray and siliceous	1, 404–1, 567
Limestone, brown, fine-textured; interbedded dark-gray calcareous shale in lower 30 ft	1, 567–1, 820
Sandstone, fine-grained, gray, calcareous, containing partings of black calcareous shale and fine-textured brown limestone	1, 820–1, 920
Limestone and shale, interbedded; limestone is fine textured and brown; shale is gray to black and calcareous; contains *Haplostiche texana* (Conrad)	1, 920–2, 395
Shale, black, calcareous; contains minor amounts of interbedded sandstone and limestone; limestone is mostly dark brown, but light-brown limestone occurs at 2,820 to 2,830 ft and contains fossil identified on sample log as "fusulinid foraminifer"; sandstone is gray, fine grained, and calcareous; *Haplostiche texana* (Conrad) reported by E. R. Lloyd	2, 395–2, 843
Cretaceous System—Finlay Limestone:	
Limestone, gray or brownish-gray, fine-textured; dark-gray calcareous shale interbedded throughout; fine- to medium-grained sandstone in lower 60 ft; *Haplostiche texana* (Conrad) reported by E. R. Lloyd	2, 843–3, 105
Cretaceous System—Cox Sandstone:	
Sandstone, gray to brown, medium-grained, loose to firmly cemented, secondary growths of quartz on many grains; partings of limestone and shale at several horizons	3, 105–3, 246
Limestone, brown, fine-textured; and interbedded sandstone and shale; sandstone is gray, fine to medium grained, weakly to firmly cemented with carbonate mineral; shale is gray to black, calcareous	3, 246–3, 368
Sandstone and shale, interbedded; sandstone is gray, brown, or white, fine to coarse grained, weakly to firmly cemented with carbonate mineral, pebbly at certain horizons; shale is brownish or greenish gray; a few partings of limestone; fossiliferous between 3,375 and 3,505 ft, shell fragments, ostracode, and *Chara*(?)	3, 368–3, 842
Cretaceous System—Bluff Mesa Limestone and Yucca Formation:	
Limestone, brown, mostly finely crystalline, pebbly at certain horizons; and interbedded gray and brown shale, gray calcareous sandstone, and limestone conglomerate; *Chara* at 3,869–3,875 ft	3, 842–4, 790

(4) *Thaxton 1 well of the Haymon Krupp Oil and Land Co*—Con.

	Depth interval (feet)
Cretaceous System—Bluff Mesa Limestone and Yucca Formation—Continued	
Limestone, brown, cherty, fine to coarsely crystalline; partings of dark-gray asphaltic shale	4, 790–5, 343
Sandstone, gray and brown, fine-grained; partings of dark-gray shale, siltstone and brown dolomite	5, 343–5, 477
Dolomite, gray or brown, fine- to coarse-textured; interbedded with black shale toward top; contains much brown and gray chert toward bottom, possibly as lenses of chert pebbles	5, 477–6, 128
Unconformity.	
Permian System—Leonard(?) Series:	
Limestone, gray and brownish-gray, coarsely crystalline, cherty. Fusulinids at 6,132–6,135 and 6,205–6,315 ft	6, 128–6, 367
Shale, gray	6, 367–6, 402

(5) *Patillo and Welch, Briggs 1 well*

Location: At northwest end of Malone Mountains. Block 73, sec. 13, Texas and Pacific Railway Co. Survey; approx 300 ft from south and west lines.
Elevation: 4,016 ft.
Total depth: 1,135 ft.

	Depth interval (feet)
No samples; possibly all alluvium	0–148
Permian System:	
Briggs Formation: dolomite and gypsum	148–645
No samples. Devil Ridge thrust somewhere in this interval	645–715
Cretaceous System:	
Undifferentiated Upper Cretaceous rocks (probably Eagle Ford Formation): sandstone, shale, siltstone	715–739
No samples	739–1, 135

Comments.—Gaps in this log greatly impair its usefulness. The thrust cannot be more than 715 feet below the collar of the well. If at 715 feet, it lies 75 feet higher than in the Krupp Briggs 1, which is located at the same elevation 600 feet due south, and the fault would have a north-south component of dip amounting to 7°.

(6) *Briggs 1 well of the Haymon Krupp Oil and Land Co.*

Location: NE¼ sec. 24, block 73, T. 7, Texas and Pacific Railway Co. Survey.
Elevation: 4,016 ft.
Total depth: 5,973 ft.

	Depth interval (feet)
Alluvium:	
Clay, light pink, sandy and pebbly, gypsiferous	0–115
Unconformity.	
Permian System—Briggs Formation:	
Dolomite and gypsum, interbedded; dolomite is dark gray to dark brown, fine to medium textured, veined with calcite and gypsum; gyspum, white, platy or finely crystalline	115–600

(6) *Briggs 1 well of the Haymon Krupp Oil and Land Co.*—Con.

	Depth interval (feet)
Permian System—Briggs Formation—Con.	
Limestone, sandstone, and gypsum; limestone is gray or brownish gray; sandstone is gray or reddish brown, calcareous; gypsum is white or reddish brown, platy or finely crystalline	600–790
Fault.	
Cretaceous System—Undifferentiated Upper Cretaceous rocks (probably Eagle Ford Formation):	
Shale, dark-gray, calcareous to marly, interbedded with gray calcareous sandstone in units several feet to several tens of feet thick; some sandstone beds in upper 100 ft contain abundant biotite	790–1, 455
Sandstone, gray, fine- to coarse-grained, calcareous, interbedded with shale; shale is mostly dark gray, very calcareous, some greenish gray	1, 455–1, 620
Shale, dark-gray, calcareous; and interbedded gray calcareous sandstone; a few partings of brown fine-textured limestone	1, 620–2, 070
Cretaceous System—Rocks of Washita age:	
Limestone, mostly brown and fine-textured, some light-gray or buff and oolitic; possibly conglomeratic at horizons within upper 100 ft; a few widely separated partings of shale and sandstone; fossiliferous, prismatic fragments of pelecypod shells around 2,150 ft, fragments of small calcareous foraminifers at 2,275–2,280 and 2,325–2,335 ft	2, 070–2, 400
Sandstone, white and gray, medium-grained, glauconitic, of angular quartz grains loosely cemented with calcite; partings of dark-gray calcareous shale and brown cryptocrystalline limestone	2, 400–2, 515
Limestone and shale, interbedded; limestone is brownish gray to dark brown, fine textured; shale is gray or brownish gray; medium-grained sandstone, loosely cemented, is interbedded in upper 80 ft; fossiliferous, fragments of pelecypod shells at 2,575–2,585 ft, scattered fragments of echinoderms (logged as crinoid stems) and one ostracode between 2,610 and 2,675 ft	2, 515–2, 900
Shale, light- to dark-gray, silty, mostly noncalcareous (but very calcareous in upper 100 ft); interbedded sandstone and limestone in minor amounts; sandstone is light to dark gray or brownish gray, fine, calcareous, argillaceous; limestone is brown, fine textured. (Probably includes Kiamichi Formation)	2, 990–3, 440
Cretaceous System—Finlay Limestone:	
Limestone, buff to dark-brown, fine-textured, sandy or pebbly (toward top and bottom); partings of dark-gray or brown calcareous shale; interbedded calcareous sandstone in lower 45 ft; fossiliferous, shell fragments and fragments of miliolid(?) foraminifers at 3,595–3,605 ft	3, 440–3, 700

(6) *Briggs 1 well of the Haymon Krupp Oil and Land Co.*—Con.

	Depth interval (feet)
Cretaceous System—Cox Sandstone:	
Sandstone, gray, of fine to coarse angular quartz grains, loosely cemented with calcite; interbedded gray or brown fine-textured limestone and gray calcareous shale	3, 700–3, 895
Shale, gray, interbedded with white calcareous fine- to medium-grained sandstone	3, 895–4, 012
Sandstone and shale, interbedded; sandstone is white to gray, fine to medium grained, calcareous or argillaceous; shale is mostly gray, reddish brown toward base; "plant remains" logged at 4,123–4,131 ft	4, 012–4, 173
Shale, gray and reddish-brown, interbedded with sandstone and limestone; sandstone is gray and reddish brown, mostly fine and calcareous; limestone is reddish gray, finely crystalline	4, 173–4, 500
Cretaceous System—Bluff Mesa Limestone and Yucca Formation:	
Limestone, gray or brownish-gray, fine to coarsely crystalline; interbedded with gray shale; in lower 190 ft shale is mostly reddish brown and is interbedded with some brown calcareous sandstone	4, 500–5, 380
Limestone, dolomite and chert; limestone is white or gray; dolomite is white; excessive amounts of chert (20 to 90 percent of 10 different samples) suggest that much of this interval is actually in conglomerate	5, 380–5, 597
Dolomite, coarsely crystalline, cherty toward top	5, 597–5, 793

(7) *Rio Bravo Oil Co., Southern Pacific Right of Way 1 well*

Location: Block 72, sec. 16, Texas and Pacific Railway Co. Survey, T. 7, 1,800 ft from north line and 1,000 ft from east line.

Elevation: 4,140 ft.

Total depth: 1,406 ft. Completed as water well, probably in sandstone of Washita age.

	Depth interval (feet)
No samples. All could be alluvium	0–60
Jurassic(?) or Lower Cretaceous(?):	
Limestone, brownish-gray, some coarsely oolitic, in association with hard argillaceous sandstone	60–460
Crosses thrust	460–555
Cretaceous System—Rocks of Washita age:	
Limestone, silty shale, and glauconitic sandstone; *Inoceramus*, ostreid, echinoderm fragments and *Haplostiche texana*—all suggesting Washita	555–1, 370
No samples	1, 370–1, 406

Comments.—This well is favorably situated to yield information on thrusting beneath the Malone Hills. Unfortunately, samples were not systematically taken, and the log shows but few "tops" for the samples logged. Accordingly the above interpretation is mostly guesswork.

On the negative side, however, the log is more useful. There is no suggestion of Briggs or other Paleozoic rocks.

Furthermore, the entire drilled section is possibly of Washita age—if indeed the Washita contains coarse oolitic limestone.

(8) *O'Keefe Fee 1 well*

Location: On east slope of Sierra Blanca peak. Block 71, sec. 23, Texas and Pacific Railway Co. Survey, T. 7. 1,320 ft from east and south lines.
Elevation: 4,995 ft.
Total depth: 1,341 ft. Completed as a water well.

	Depth interval (feet)
Alluvium(?). No samples	0–60
Cretaceous System.—Rocks of Washita age:	
Limestone, brownish-gray or gray, commonly sandy, shaly toward base; interbedded with sandstone and shale; sandstone is white or gray, fine grained, limy, locally argillaceous; shale is dark gray, soft to hard, commonly sandy; fossiliferous, *Lagena* sp., *Haplostiche texana* (Conrad)?, *Nodosaria communis*, large echinoid spines, and fragments of oyster shells	60–235
(Sill of igneous rock(?); logged as "hard cream-colored speckle ash")	235–310
Shale, brown to black, silty; contains shell fragments and echinoid spines	310–360
(Sill of igneous rock(?); logged as "hard cream-colored ash")	360–400
Limestone, grayish-brown, red, pink, yellow, tan; sandy, grading into fine sandstone at base; few *Haplostiche texana*, *Pecten* sp., oyster fragments	400–420
Cretaceous System—Finlay Limestone:	
Limestone, tan to dark-gray; fossiliferous, contains fragments of "large *Orbitolina*" (= *Dictyoconus walnutensis*?) at 475–480 ft	420–550
Sandstone, pinkish- to reddish-brown	550–560
(Sill(?) of igneous rock; from 560 to 627 ft logged as "whitish crystalline igneous rock," below 627 ft logged as tuff)	560–890
Limestone, dark-gray; fossiliferous, contans shell fragments and large arenaceous foraminifers	890–950
Cretaceous System—Cox Sandstone:	
Shale, dark-gray, silty, lignitic	950–970
Sandstone, gray, of fine to coarse clear subangular grains; interbedded light-gray to green clay shale	970–1, 100
Shale, sandstone, and limestone, interbedded; shale is gray, silty; sandstone is mostly fine grained calcareous; limestone is sandy	1, 100–1, 140
Limestone, gray, sandy, or earthy	1, 140–1, 170
Sandstone, greenish-gray, fine-grained	1, 170–1, 190
(Sill of igneous rock(?); logged as "dark-gray metamorphosed * * * rock," "limestone bearing abundance of ash," et cetera)	1, 190–1, 215

(8) *O'Keefe Fee 1 well*—Continued

Cretaceous System—Cox Sandstone—Con.	*Depth interval (feet)*
Sandstone, medium- to coarse-grained; interbedded with reddish-brown and gray shale; possible thin sill of igneous rock crossed at 1,240–1,250 ft	1, 215–1, 330
No sample	1, 330–1, 341

Comments.—If the igneous bodies are omitted, 200 feet of Finlay was penetrated—only 20 feet more than measured across the valley at Triple Hill. A dip of 25° would account for the interval penetrated in the well.

(9) *Joe O'Keefe: Water well 1*

Location: Block 61½, NE¼ sec. 3.
Elevation: Not given.
Total depth: 645 ft(?).

Cretaceous System—Cox Sandstone:	*Depth interval (feet)*
Sandstone and some shale	0–345
No samples; no record	345–505
Interbedded sandstone, shale, and sandy limestone, parted by sills of igneous rock logged as tuff	505–645

(10) *H. H. Henshaw Love 1*

Location: Off north end of southern Quitman Mountains block 67½, NE¼ sec. 9, Public School Land.
Elevation: 4,383 ft.
Total depth: 690 ft.

Quaternary System—Alluvium:	*Depth interval (feet)*
No samples	0–15
Clay, light yellowish- or reddish-brown, sandy and pebbly; interbedded with limestone gravel between 175 and 235 ft	15–270
Unconformity.	
Cretaceous System—Bluff Mesa Limestone or Cox Sandstone:	
Limestone and sandstone, interbedded; more limestone than sandstone; limestone is gray to brown, fine textured; sandstone is gray to reddish brown, hard, some quartzitic; single ostracode found at 380–400 ft	270–400
Cretaceous System—Bluff Mesa Limestone:	
Limestone, very dark gray to dark brownish-gray, fine-textured, some silty; sparsely fossiliferous, miliolid foraminifers, oyster shells, echinoid spines, and ostracodes; *Orbitolina texana* (Roemer) at 680–690 ft	400–690

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