Geology of Big Bend National Park, Brewster County, Texas

By | Ross A. Maxwell
John T. Lonsdale
Roy T. Hazzard
John A. Wilson

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

SAM HOUSTON

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

MIRABEAU B. LAMAR

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JOHN TIPTON LONSDALE

1895–1960

Memorial to John Tipton Lonsdale

John Tipton Lonsdale, distinguished geologist and authority on the geology of Texas, died at his home in Austin, Texas on October 5, 1960. He was 64 years old. Death came suddenly as the result of a heart attack. Although his close friends and associates knew that he had been in less than normal health for a few months, no one realized that his ailments were serious, for he had been active with his professional and administrative duties as Director of the Bureau of Economic Geology at The University of Texas until two days before his death. His wife, Edna Gertrude (Von Arman) Lonsdale, whom he married August 13, 1921; a sister, Miss Bernice Lonsdale, Holly Hill, Florida; and a brother, Richard R. Lonsdale, Daytona Beach, Florida, survived.

John Lonsdale was born November 8, 1895 at Dale, Iowa, the eldest son of Eva Mary (Conner) and John Dye Lonsdale. He received his elementary education at Dale, Iowa, and his high school training at Guthrie Center, Iowa. He was awarded the B.A. degree in 1917 and the M.S. degree in 1921, both from the University of Iowa. The Ph.D. degree was earned in 1924 from the University of Virginia.

John Lonsdale was an officer in the United States Army from 1917 to 1919, serving as First Lieutenant. He received citations for bravery from both the United States and Italian governments. John T. Lonsdale was a staunch patriot, and his strong interest in military affairs continued undiminished after his retirement with the rank of colonel in 1953. In recognition of his military service, his ashes were interred in Arlington National Cemetery.

During undergraduate training, he held positions as field assistant with both the Iowa and Colorado Geological Surveys, but his distinguished professional career began in 1921 when he served as Assistant Professor of Geology at the University of Virginia and Geologist for the Virginia Geological Survey. In 1924 he became Assistant Professor at the University of Oklahoma and Geologist with the State Geological Survey. In 1925 he came to The University of Texas as a Geologist on the staff of the Bureau of Economic Geology.

In 1928, John Lonsdale was appointed Professor of Geology and elected Head of the Department of Geology at the then Agricultural and Mechanical College of Texas, where he became the leader in developing a strong geological curriculum and was chiefly responsible for the planning and design of a new geology building on the College Station campus. While at College Station, he also served part-time as geologist for the Missouri Pacific Railroad Company. From Texas, John Lonsdale went to Iowa State College at Ames where, except for military leave, he was Professor of Geology and Head of the Geology Department from 1935 to 1945. He returned to The University of Texas in 1945 as Director of the Bureau of Economic Geology, Professor of Geology, and member of the Graduate Faculty, the positions which he held at the time of his death.

John Lonsdale held membership in many scientific and honorary societies, including Sigma Xi, Sigma Gamma Epsilon, American Association of Petroleum Geologists, American Institute of Mining, Metallurgical, and Petroleum Engineers, American Geophysical Union, Society of Economic Geologists, and Society of Economic Paleontologists and Mineralogists. He was a Fellow of The Geological Society of America, the Mineralogical Society of America, and the American Association for the Advancement of Science. At the time of his death he was President-elect of the Association of American State Geologists.

Lonsdale's career was marked by faith-

ful service on the various committees of his professional societies, including the Policy and Administration Committee of The Geological Society of America; the Committee on Stratigraphic Nomenclature of the Association of American State Geologists; the Research, Business, and Well Sample Committees of the American Association of Petroleum Geologists; the Committee for Nomination of Fellows to the Mineralogical Society of America. He also served on the Texas Topographic Mapping Advisory Committee; Mapping Committee of the Texas Water Conservation Association; Geology and Minerals Committee of the Arkansas, White, and Red River Basins Interagency Committee; Texas Advisory Committee on Conservation Education; and the Natural Resources Committee of the Houston Chamber of Commerce. A special task assigned by University officials soon after his return to Texas in 1945 was to aid in the recruiting and building of an outstanding Department of Geology. His suggestions and guidance as a member of the Budget Council had a marked effect on the Department's growth.

John Lonsdale's contributions to geologic research ranged from detailed analyses of complex rock and mineral systems to the economic geology of many different industrial mineral products. His work always had a strong practical slant toward the economic importance of a mineral deposit. As Director of the Bureau of Economic Geology, he began an investigation of the State's mineral resources, which emphasized minerals other than oil and gas. The full importance of this work has not been realized, but in the future it will no doubt rank as one of his greatest contributions. Among his specialities were investigations of ground-water resources in south Texas, igneous rocks of the Balcones fault region, igneous rocks of the Terlingua-Solitario region, and igneous rocks of Big Bend National Park. The latter work, nearly complete at the time of his death, is herewith published as part of the report on the Park area which this memorial introduces.

John Lonsdale was active in the Austin Rotary Club and gave liberally to their projects, and he also gave liberally to charitable organizations. He was a hunter, gun collector, delightful companion in the out-of-doors, and respected professor who had the ability to develop a strong bond of friendship with his students. Many of these students now hold high positions in the scientific and business world, but they continued to correspond and visit with their former professor up to the time of his death, and many traveled hundreds of miles to Austin in order to pay their last respects on October 7, 1960.

John Lonsdale had not only brilliant research and teaching records and an outstanding military career, but he was also an administrator capable of planning and carrying out programs involving the skills of numerous specialists in diversified fields of geology and allied sciences. He was an honored, respected, and understanding leader, who was always generous in extending recognition to both colleagues and employees. He was a pleasant, modest, unassuming man who did not seek the numerous and varied honors that came to him. He was a stimulating but quiet conversationalist with the poise of one who knew his own ability and qualifications. There was a pleasant and congenial atmosphere in the Lonsdale home where he and Mrs. Lonsdale had maintained that mutual trust, honor, love, and affection for 40 years. The real worth of a life is not measured by its length but by its quality, and John Lonsdale was a man who lived a full life, always striving to maintain the highest standards. The geology profession has lost one of its truly great members.

Geology of Big Bend National Park, Brewster County, Texas

Ross A. Maxwell,[1] John T. Lonsdale,[2] Roy T. Hazzard,[3] and John A. Wilson[4]

ABSTRACT

Big Bend National Park lies in the southernmost tip of Trans-Pecos Texas where the Rio Grande makes a deep southward bend. Paleozoic rocks occur only in the northern part of the Park; Cretaceous rocks are the most widely distributed but thick deposits of Tertiary volcanic rocks crop out in the central Park area. Intrusive igneous rocks are common and are an important part of the geology. Most of the highest elevations are bordered by gravel-covered pediments; detritus has accumulated in some interfault block valleys.

A wide variety of sedimentary, extrusive volcanic, and intrusive igneous rocks are exposed in the Park, and the span of geologic time represented by them extends from early Paleozoic to Recent. The total thickness of sedimentary and extrusive volcanic rocks is about 13,800 feet, of which the Paleozoic comprises about 1,400 feet, the Comanchean 2,000 feet, the Gulfian 3,100 feet, the Tertiary 7,300 feet, and the alluvium and colluvium as much as 500 feet.

Some established stratigraphic nomenclature is used but a number of new names are introduced to designate the lithostratigraphic units that occur in the Park. Paleozoic rocks of the Ouachita system, like some of the units in the Marathon Basin, crop out in the Persimmon Gap—Dog Canyon area, and Marathon Basin nomenclature is used for these. Comanchean rocks, mainly massive limestone with minor amounts of nodular marly limestone, marl, and clay, occur most extensively along the eastern and western sides of the Park. Gulfian rocks are flaggy, argillaceous limestone, chalk, marl, clay, bentonitic clay, and sandstone. They occur mainly in the central part of the Park. Some established names for the Cretaceous strata are retained, some names are elevated to group status, and a number of new names are introduced. Tertiary formations are sandstone, clay, tuffaceous rocks, pyroclastic rocks, and lava. They crop out mostly in the central area and new names are introduced for all but one of the lithostratigraphic units. Intrusive igneous rocks include numerous dikes, sills, large, irregular tabular bodies, laccoliths, and several conspicuous bosslike masses. Much of the bedrock is covered by a mantle of alluvium or colluvium.

Many of the stratified rocks contain fossils that locally are abundant. Marine invertebrates, mainly ammonites, pelecypods, and gastropods, occur in the Comanchean and early Gulfian formations. Dinosaur bones and teeth, turtle and crocodile remains, shark teeth, fish bones, and fossil wood occur in the upper Gulfian terrestrial deposits. Mammalian remains are present in some of the Tertiary formations. Potassium-argon ages are available for some of the lavas. Others have distinctive mineralogy or characteristic mineral assemblages. Some have been analyzed chemically and some have been the subject of paleomagnetism studies. These various data have been useful in correlation.

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The rocks crop out in a variety of attitudes and locally are complexly deformed. Horizontal strata are rare; anticlines, synclines, domes, and tilted fault blocks are common. Major folds and thrust faults were formed during the Laramide orogeny; the major normal faults are Tertiary. Most folds and faults trend northwest; several of them extend southeastward into Mexico, and some extend northwestward beyond the Park boundary.

The Santiago Mountains and Sierra del Carmen of Texas form a highland on the east side of the Park. The backbone ridge of the Santiago Mountains is an asymmetric anticline, overturned toward the southwest, with thrust faults along its crest. The deformed rocks are Comanchean. In the Persimmon Gap—Dog Canyon area, erosion has exposed pre-Cretaceous thrust fault sheets of Paleozoic rocks. These Paleozoic thrust sheets, along with blocks of Cretaceous rock, were thrust southwestward during the Laramide orogeny. The Sierra del Carmen is a broad arch of Comanchean rocks that has been broken by a series of normal faults. Some of the normal faults cut Tertiary volcanic rocks; others extend northwestward cutting the overturned folds and thrust faults in the southern Santiago Mountains.

Mesa de Anguila and the southern end of the Terlingua uplift form highland areas along the western side of the Park. Mesa de Anguila is a tilted fault block, mainly Comanchean limestone, that is bordered by the Terlingua fault zone along the northeast side. Southwest of the Terlingua fault zone, Cretaceous rocks are broken by numerous normal faults. Some of these extend northwestward beyond the mesa and the Park boundary where they cut Tertiary volcanic rocks.

The Terlingua uplift is a broad irregular arch that has its steepest dips and a few small thrust faults along its southwestern margin. The broad uplift and the thrust faults were formed during the Laramide orogeny. The Comanchean and lower Gulfian rocks have been displaced in several grabens and penetrated by intrusions. The Solitario, near the north end of the Terlingua uplift, is a large intrusive dome. The crest has been breached, exposing Paleozoic rocks of the Ouachita system. In some places solution of the limestone has caused collapse which extended upward into the overlying rocks. The breccia pipes in the Terlingua quicksilver district formed in this way.

Between the Mesa de Anguila—Terlingua uplift on the west and the Santiago Mountains—Sierra del Carmen on the east is the Sunken Block, a valley about 40 miles wide. Most of the Sunken Block is floored by Gulfian rocks but near its center are the Chisos Mountains, formed of Tertiary extrusive and intrusive rocks that rise 2,000 feet above the highest elevations in the mountainous areas on either side. The principal folds and faults in the Sunken Block trend northwest paralleling the alignments formed during the Laramide orogeny and the principal structures in the eastern and western highland belts. The main post-Cretaceous fold system extends northwestward from Mariscal Mountain, passes through the central Chisos Mountains, and includes the Christmas Mountains dome. These structures were later deformed by two periods of intrusive doming. Minor folds flank the post-Cretaceous structural axes on both sides, and there are a few large Tertiary intrusions and many dikes and sills that do not seem to be related to the older structural trends.

The asymmetric folds and thrust faults in the Santiago Mountains and Mariscal Mountain, the belt of folds extending northwest from Mariscal Mountain, and the Terlingua uplift were formed during the Laramide orogeny. Some of the uplifted areas were eroded but the structurally high areas persisted so that the earliest Tertiary rocks were deposited in a basin between the deformed belt in the Santiago Mountains on the east and the folded belt that extended northwest from Mariscal Mountain. Tertiary volcanic rocks covered part of the area in late Middle Eocene and all of the area during the Late Eocene. Post-Late Eocene uplift raised the Chisos

Mountains, displacing and deforming the belt of folded Cretaceous rocks that extends northwest from Mariscal Mountain, and also formed the Punta de la Sierra fault belt southwest of the Chisos Mountains. Some of the normal faults in the Cow Heaven anticline, Mariscal Mountain, Santiago Mountains, and the Sierra del Carmen are post-Late Eocene. Erosion substantially reduced the thickness of Late Eocene rocks in the Chisos Mountains and formed fault line escarpments along faults that tilted the Late Eocene rocks southwest of the mountains.

Extensive activity during the Oligocene deposited the youngest exposed volcanic rocks on an eroded surface developed on the Late Eocene rocks. Post-Oligocene intrusions further raised the central Chisos Mountains and further deformed the Cretaceous formations that were first elevated during the Laramide orogeny, the Tertiary volcanic rocks that were raised and faulted by post-Late Eocene uplift, and the Oligocene volcanic rocks. Normal faults that are probably Oligocene were formed west and southwest of the Chisos Mountains; the Burro Mesa—Castolon—Terlingua fault belts and the faults that outline the boundaries of the Sunken Block were probably formed at the same time. A late epoch of deformation tilted some of the Miocene bone-bearing rocks and tilted and perhaps faulted some of the oldest alluvial and colluvial deposits. There probably was late uplift along the Terlingua fault zone at the mouth of Santa Elena Canyon.

The subsequent history in the Park is dominantly that of erosion. Where the Rio Grande crosses folds and tilted fault blocks, it has carved deep, steep-walled canyons. The Rio Grande and its tributaries have removed large quantities of the weakly resistant rocks from the Sunken Block, leaving the hard rock masses standing in bold relief; most of these are bordered by conspicuous gravel-covered pediments. Weathering and erosion along joints have produced spectacular rock columns, alternating hard and soft rock layers were eroded to form stepped topography, and resistant igneous rock or hard limestone commonly caps the high mesas.

INTRODUCTION

Ross A. Maxwell

Location and General Description

The name Big Bend is applied somewhat loosely to a region lying within the great southward bend made by the Rio Grande between long. 102°50′ and 104°50′ W. A convenient arbitrary northern boundary is lat. 30° N., which is approximately along the south side of the Marathon Basin and the north flank of the Chinati Mountains. The Rio Grande is the southern boundary. The region is one of the last geologic and historic frontiers in Texas around which a great folklore has accumulated, including legends concerned with buried treasure, lost mines, Indian raids and battles, cattle rustlers, and bandit raids. The region is sparsely settled, the principal human activities being ranching and, in the past, quicksilver and silver mining. The region is along the International Boundary, far from railroads, and until recently not served by highways; hence it retains more features of the Old West than perhaps any other area of its size in the United States.

The harsh, physically inhospitable arid Big Bend area either attracts and fascinates or utterly repels the visitor. Instead of dashing mountain streams, grassy glades, and towering forests, there are bleak, drab, desert lowlands and stark bare mountains that shimmer in summer heat and are apparently devoid of life. If the visitor lingers, however, he learns that the higher mountains are a treasure house of exotic plant and animal life; at sunset drab lowlands come to life with birds, mammals, and reptiles in surprising numbers. The geologist is impressed with the variety of geologic phenomena so plainly exhibited in this arid setting. As in many parts of the Southwest, there are spectacular examples of land forms developed under semiarid conditions, and the field geologist can observe structural relationships and stratigraphic sequences in detail in the bare rock exposures, even from a distance. The major structures are clear and have in part determined the present land forms.

Big Bend National Park is at the southern tip of the Big Bend region (fig. 1) and includes both lowlands and mountains. The area was selected for a National Park largely because of its geological features and the display of plant and animal life in the southwestern mountains. The Park includes about 708,281 acres of Federally owned land; it is not yet completely developed, but work is in progress to make much of the Park accessible to visitors.

Geologic Setting

In the Big Bend region Cretaceous marine and terrigenous sedimentary rocks, Tertiary terrigenous sedimentary and pyroclastic rocks, lava flows, and igneous intrusions are prominent (table 1, p. 6). The region includes three areas of exposed Paleozoic rocks like those in the Marathon Basin to the north. These are (1) several exposures of pre-Permian limestone and shale in the southern Santiago Mountains, (2) a larger exposure of pre-Permian shale and novaculite in the center of the Solitario, and (3) Permo-Pennsylvanian carbonate rocks in the Shafter and Pinto Canyon areas of the Chinati Mountains (Pl. I). Exposures of metamorphic rocks, probably

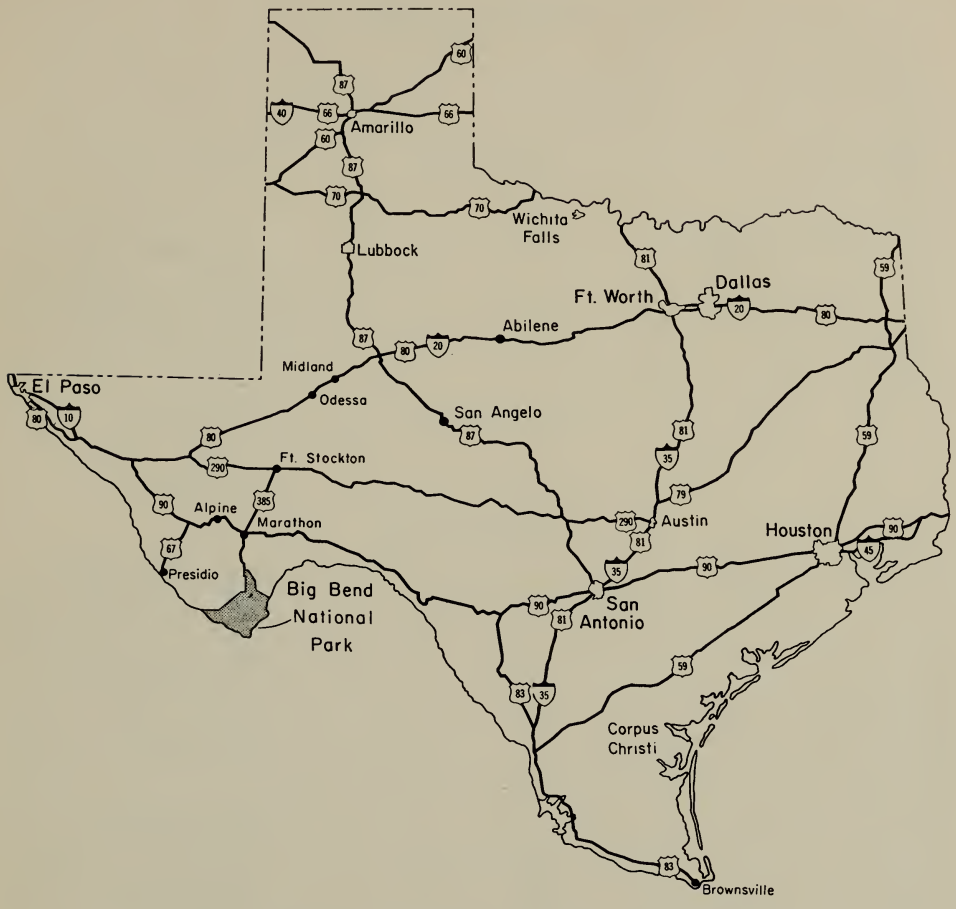


FIG. 1. Index map showing location of Big Bend National Park.

of Paleozoic age, occur across the Rio Grande in Coahuila, Mexico, immediately south of Big Bend National Park.

The geologic map (Pl. II) extends beyond the National Park boundaries (fig. 1) so as to include the Christmas Mountains, a domical uplift, Mesa de Anguila, a fault-block mesa on the west side of the Park, and the southern Santiago—Sierra del Carmen ranges on the east. The two latter uplifts form approximate boundaries of an elongate structurally low area that Udden (1907a, pp. 80–81) named the Sunken Block. Comanchean rocks are prominently exposed in the Mesa de Anguila and Santiago—Sierra del Carmen ranges and also project within the Sunken Block at Maris-cal Mountain, Sierra San Vicente, and the Christmas Mountains. The sides of the structural depression are formed elsewhere by Gulfian rocks, overlying which, in the Chisos Mountains in the central area, are several thousand feet of Tertiary clastics, pyroclastics, and lavas. The stratified rocks are intruded by igneous rocks of both Cretaceous and Tertiary ages.

Most major faults in the Park trend northwest and some are displaced several thousand feet. They cut rocks of all ages and were formed during periods of post-Paleozoic, post-Cretaceous, post-Upper Eocene, and post-Oligocene uplifts; a few perhaps are as young as Late Tertiary or Early Pleistocene.

TABLE 1.—Generalized stratigraphic classification in Big Bend National Park.

TIME STRATIGRAPHIC UNITS				ROCK STRATIGRAPHIC UNITS			
SYSTEM	SERIES		STAGE	GROUP	NAME OF FORMATION	THICKNESS (*FEET*)	LITHOLOGY
QUATERNARY	PLEISTOCENE TO MIOCENE				Older alluvium deposits (includes Udden's Dugout Clays and Gravels)	100– 500	Clay, silt, sandstone, and conglomerate
TERTIARY	OLIGOCENE OR YOUNGER		POST-DUCHESNEAN	Big Bend Park	South Rim Formation	1,000–1,500	Lava flows, ash beds, tuff, flow breccia, irregularly bedded sandstone, and conglomerate
			DUCHESNEAN				
	EOCENE	Upper	UINTAN?		Chisos Formation	1,500–2,600	Indurated tuff interbedded with clay, mudstone, tuffaceous sandstone, ash beds, lavas, sandstone, and conglomerate
		Middle	BRIDGERIAN		Canoe Formation	1,170	Base is a massive yellow cross-bedded sandstone overlain by tuff, mudstone, tuffaceous sandstone, indurated tuff, and lavas
		Lower	WASATCHIAN	Tornillo	Hannold Hill Formation	356– 770	Soft, gray, and yellowish-gray conglomeratic sandstone and varicolored and mottled clay
	PALEOCENE		TIFFANIAN OR TORREJONIAN		Black Peaks Formation	850 plus	Varicolored clay interbedded with ledge-forming, cross-bedded, yellow, buff, and gray sandstone and lenses of conglomerate
			PUERCAN				
CRETACEOUS	GULFIAN		MAESTRICHTIAN		Javelina Formation	350– 850	Gray, dull green, blue, red, yellow, purple, brown, black, and white clay, with thin layers of sandstone; clay commonly bentonitic; contains fossil wood and dinosaur bones
			CAMPANIAN		Aguja Formation	800–1,300	Nonmarine dark carbonaceous clay, some silt, and layers of coal interbedded with brown and yellowish-brown sandstone—300–700 feet thick; contains fossil wood and dinosaur bones
			SANTONIAN				Marine sandstone and silty clay, with a shelly sandstone generally present at the base—500–700 feet thick
			CONIACIAN	Terlingua	Pen Formation	200– 600	Dark grayish-blue gypsiferous marl and clay that weathers yellow, with concretionary limestone and layers of calcareous sandstone
					BOQUILLAS FORMATION: San Vicente Member	330– 400	Gray and bluish-gray chalk and gray to buff argillaceous flaggy limestone
			TURONIAN		BOQUILLAS FORMATION: Ernst Member	475	Gray, buff, and yellowish-brown flaggy limestone interbedded with gray and buff marl
	COMANCHEAN		CENOMANIAN		Buda Limestone	100	Whitish, dense, brittle limestone and nodular limestone interbedded with marl
					Del Rio Clay	1– 125	Light gray and yellow clay, clay-shale, and thin-bedded limestone
		ALBIAN	Upper		Santa Elena Limestone	750– 850	Mostly massive, heavy-bedded, dense, cherty limestone, with thin marly limestone beds near base
			Middle		Sue Peaks Formation	75	Shale, marl, and thin marly, nodular limestone ledges
					Del Carmen Limestone	350– 450	Massive, heavy-bedded, dense, cherty limestone
					Telephone Canyon Formation	40– 130	Thin, nodular, marly limestone and marl
					Maxon Sandstone	10	Medium-grained, calcareous sandstone
			Lower		Glen Rose Limestone	600	Dense limestone interbedded with calcareous shale; conglomerate and coarse sandstone at base; exposed on flanks of Persimmon Gap and the Solitario
ORDOVICIAN TO PENNSYLVANIAN					Paleozoic rocks undifferentiated; considered equivalent to the Tesnus, Caballos, and Maravillas Formations, and probably older limestone and shale	Unknown	Strongly folded rocks, including slightly metamorphosed shale, chert, novaculite, and limestone; exposed at Persimmon Gap and in the Solitario
					Metasedimentary rocks	Unknown	Fine-grained schist, metaquartzite, phyllite, and marble exposed in the Sierra del Carmen near Boquillas, Coahuila, Mexico

History of Work

Between authorization of Big Bend National Park in 1935 and its establishment in 1944, the National Park Service sponsored scientific investigations of the Park area. Maxwell, at that time geologist for the National Park Service, and his associates made a reconnaissance geological survey in 1936 and 1937. At about the same time, Lonsdale (1940) studied the igneous rocks in the Terlingua-Solitario area, west of the Park area. He and Maxwell planned to extend these studies into the Park area with the aid of a grant from the Penrose Bequest of The Geological Society of America. Although some field work was done by them during the summer of 1941, it was interrupted by World War II and was not resumed until 1946. Intermittent field and office work was done by Lonsdale and Maxwell between 1946 and 1952. After this, Lonsdale worked intermittently on the project until his death in 1960. Maxwell worked continually on the project from 1952 to 1963 except for 20 months in 1960–1961.

Previous Geologic Work

The general geologic features of the Big Bend region were described in various early reports, although most of these gave few details. R. T. Hill (1902) gave a general account of the area and (1901b) published a vivid narrative of a boat trip through the Rio Grande canyons. Udden (1907a) presented an excellent description of the major features of the region and its basic stratigraphy and structure as the result of a reconnaissance survey, but his report is not accompanied by a map. Baker and Bowman (1917) reported on a later reconnaissance in southeastern Trans-Pecos Texas and described the Santiago—Sierra del Carmen area in some detail. Sellards (1933), Adkins (1933), and Plummer (1933), in later summaries of the geology of Texas, included information on the Big Bend region. The handbook of Cretaceous fossils by Adkins (1928) contains descriptions and illustrations of many fossils which occur in the Big Bend region. Baker's (1935) summary of the structure of Trans-Pecos Texas includes discussions of the region. Ross (1935) and Schuette (1930) studied the quicksilver deposits in the Terlingua district and discussed briefly the structure and quicksilver occurrence at Mariscal Mountain. Lonsdale (1940) described the igneous rocks of the Terlingua-Solitario area. Maxwell (1941), Maxwell et al. (1949), and Lonsdale et al. (1955) prepared guidebooks for the Park and adjacent parts of the Big Bend region. Yates and Thompson (1959) reported on the geology and quicksilver deposits of the Terlingua district.

Acknowledgments

The authors of this report are indebted to many individuals, scientific societies, Federal and State organizations, and private corporations for their varied assistance and cooperation.

Special recognition is given to:

(1) The National Park Service, which approved the joint project of Maxwell and Lonsdale, cooperated fully, and gave permission for publication of the work which was done by Maxwell under its auspices.

(2) The Geological Society of America, which provided funds from the Penrose Bequest to support the work at a time when funds from other sources were not available.

(3) The Texas State Parks Board, which furnished the senior author with office

space, stenographic aid, drafting facilities, and limited field expenses during the early days of the project.

(4) Gulf Oil Corporation, which, through their trainee program, authorized R. T. Hazzard to compile the planetable map of the Persimmon Gap—Dog Canyon area and to measure the stratigraphic sections elsewhere in the region.

Besides these organizations, the authors acknowledge the assistance of the late Charles N. Gould, formerly Regional Geologist, National Park Service; Howard E. Rothrock, formerly Assistant Chief of the Naturalist Division, National Park Service; Clyde P. Ross, geologist, U.S. Geological Survey; Robert C. Redfield and the late Hugh M. Eley, who were field assistants and who made most of the early fossil identifications; James E. Wilson, a field assistant; the late W. S. Adkins, who spent many days in the field and advised the writers on Cretaceous stratigraphy and fossil identification; John T. Twining, who gave field assistance and made fossil identifications; Keith Young, who during recent years made some of the fossil identifications and advised the senior author regarding stratigraphic nomenclature and correlation problems; and the following who critically read all or parts of the manuscript: F. Earl Ingerson, Sr., and J. Hoover Mackin, Department of Geology, The University of Texas, and Philip B. King, U.S. Geological Survey.

LAND FORMS

Ross A. Maxwell

General Outline

Big Bend National Park (Pl. I) includes the Sunken Block described by Udden (1907a, pp. 80–81) and Baker (1935, pp. 172–180), which is bounded on the southwest by Mesa de Anguila, a fault block with an altitude above 3,500 feet, and on the east by the Sierra del Carmen—Santiago ranges, a series of fold and fault block ridges, with the higher ridge crests above an altitude of 4,000 to 5,000 feet. The altitude in the Sunken Block is less than 3,500 feet but many ridges, mesas, and intrusions rise above the general plain. The Chisos Mountains, near the center of the Sunken Block, were raised by intrusions, and several of the peaks are above an altitude of 7,000 feet. The Rio Grande, with an altitude of 2,000 feet in the Park, is only about 16 miles south of Emory Peak, the highest elevation (7,835 feet) in the Chisos Mountains.

The Park embraces Cretaceous and Tertiary intrusive igneous rocks, massive- and thin-bedded Cretaceous limestone, shale and clay, and great piles of Tertiary lava, volcanic ash, sandstone, and thick gravel beds. Topographic features include neck-like igneous peaks, steep cuesta escarpments, fault scarps, fault-line scarps (both obsequent and resequent), mesas and buttes, dissected mountain divides, isolated rounded hills, dissected pediment slopes, wide valley flats, and steep-walled canyons. Depositional features include ancient valley fill deposits, terraces, and pediment gravels, talus deposits, and alluvial fans. Resistant igneous rocks and massive limestones form most of the mountains, mesas, and other high topographic features, and the valleys are underlain by weak rocks (fig. 2). Intrusions emplaced in the weaker rocks are topographically prominent.

Climate and vegetation.—The Park has an average annual rainfall of less than 15 inches. The highest summits normally have the greatest rainfall; some of the lowlands bordering the Rio Grande average less than 5 inches annually. Most of the rainfall comes during the hot summer months in the form of thundershowers that are of short duration but often of great intensity and sometimes accompanied by violent winds. Summer temperatures are commonly greater than 100° at elevations below 3,000 feet but are in the low 90's at elevations above 5,000 to 6,000 feet. The summer nights are normally cool and windy. Many of the blizzards that roar across the Great Plains bypass the Park area, but generally at least one storm brings light snowfall to the mountain tops each winter, and sub-zero temperatures have been recorded at elevations of 5,000 or more feet. The average mean annual temperature for Brewster County is approximately 63°.

Like most parts of Trans-Pecos Texas, the Park has sparse vegetation. The principal exception is high in the Chisos Mountains, where there are small stands of Ponderosa pine, aspen, maple, Douglas fir, and Arizona cypress. These plant communities are in sheltered sites where the plants have managed to survive in the semiarid climate alongside the more rugged varieties of oak, pinyon, juniper, madrona, yucca, agave, and several species of cacti.

The plant communities gradually change downslope in response to the more severe, semiarid environment. In the lowest parts of the mountains and on the semiarid flats flanking them are a large variety of hardy plants that are adapted to this terrain and climate. Relative abundance of some of



FIG. 2. Looking north from the Chisos Mountains at a terrain produced by differential erosion of hard and soft rocks. Christmas Mountains upper left, Chisos Pen anticline lower left. Oak Creek flows between the Christmas Mountains and the north end of the anticline, and Cottonwood wash crosses the fold at Chisos Pen.

these plants is related to lithology and topography. Rocky pediments, massive limestone mesas, and most igneous rock slopes are normally covered with lechuguilla and scattered bunches of sotol, candelilla, creosote bush, mariola, prickly pear, needle, and chino grass. On the flatter parts of the ridges, where deeper soil is present, there are some dense stands of silverleaf (ceniza), tarbush, and scattered specimens of mesquite, catclaw, ephedra (Mormon tea), allthorn, coldenia, cholla, Indian paintbrush (painted cup), and snakeweed (broomweed) (fig. 3). The arroyos that drain the pediment or mesa slopes are choked in places with thickets of mesquite or catclaw, and in some places there are individual plants or small clumps of Apacheplume, Mexican-buckeye, Texas-persimmon, yellow trumpet, and guayacan; in the better-watered parts of the arroyos there are commonly cottonwood, ash, and clumps of buttonbush. On overflow flats along the arroyos, whitebrush grows in almost impenetrable thickets, and at some of the lower outwash slopes, tasajillo is abundant.

On some limestone and basalt gravel slopes, ocotillo growths are common. Certain limestone and gravel-floored valleys in the Sierra del Carmen are famous for yucca (Spanish Dagger), and during World War I, guayule (rubberplant) was harvested from similar areas. Little club mosses (Resurrection plants) are thick on many limestone ledges in the Sierra del Carmen, and locally, near the Rio Grande, the lechuguilla has been replaced by hechtia, a member of the pineapple family. Bluebonnets (lupine) are abundant during some seasons along the broad gravel washes; verbena, pentstemon, prickly poppy, asters, and various yellow composites color the roadsides. Mesquite, screw-



FIG. 3. View of eastern side of the Chisos Mountains. Except for lechuguilla and chino grass, there is little but barren rock ledges exposed in the upper mountain slopes. The lower pediment slopes (foreground) are commonly covered with hardy semiarid vegetation species including lechuguilla, allthorn, catclaw, coldenia, silverleaf, paintbrush, and dagger.



FIG. 4. Weathering and erosion along vertical joints cause large boulder falls locally to choke the stream; the larger boulders are about 40 by 40 feet. (Photograph by Peter Koch.)

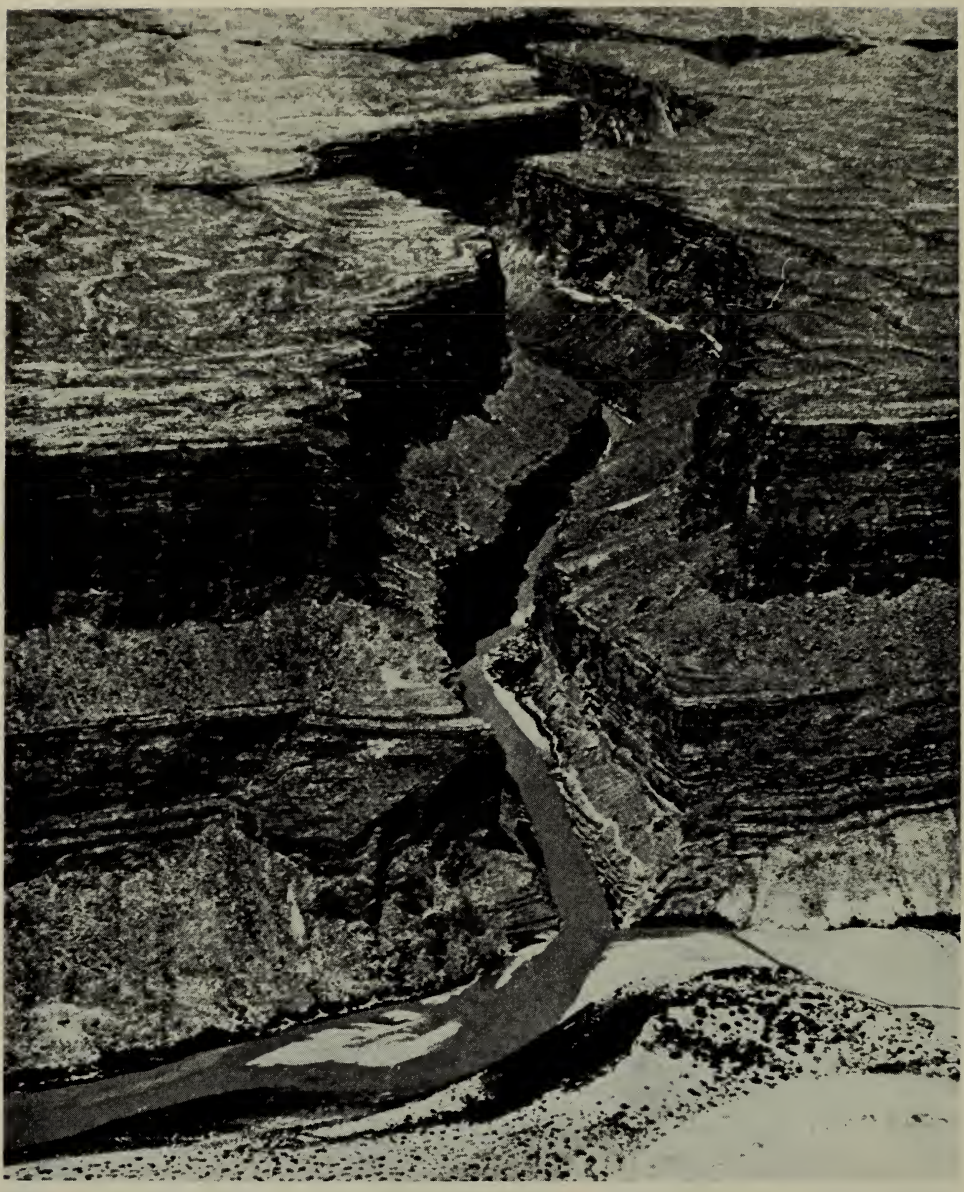


FIG. 5. Looking west into Santa Elena Canyon, a gorge in Comanchean limestone at Mesa de Anguila. (Photograph by Hunter's of Alpine, Texas.)

bean (Tornillo), tree tobacco, and carrizo cane are thick in the low valleys (vegas) along the Rio Grande.

Erosion processes.—Running water is the chief erosion agent. Although the annual rainfall is small, much of it comes as torrential downpours, and sheet wash is effective on the slopes. Undermining, sapping, and marginal fragmentation reduced the more resistant rocks that cap the higher elevations. Steeply dipping joints are an important factor in rock wasting and recession of the cliffs because they permit the downward seepage of water that causes weathering and spalling. When the fragmental material reaches the foot of an es-

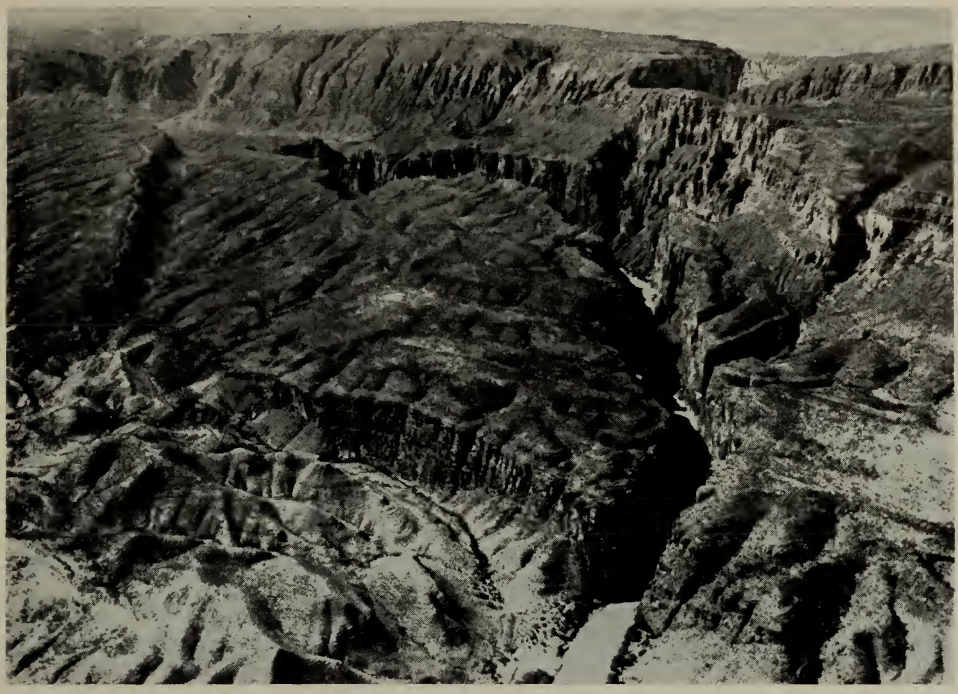


FIG. 6. Mariscal Canyon cut by the Rio Grande through folded and faulted massive Cretaceous limestone at Mariscal Mountain. This canyon is 500 to 800 feet wide near the top and is about 1,650 feet deep.



FIG. 7. Boquillas Canyon cut by the Rio Grande in massive Comanchean limestone in the Sierra del Carmen.

carpment or falls into a canyon, it is rolled about and is eventually carried away by streams (fig. 4). Although the wind appears to blow constantly and occasionally reaches near-hurricane velocities, it is of secondary importance to the stream erosion process, as the scanty vegetation and lag gravel offer more effective protection against erosion by wind than by water. There is no evidence of glaciation in the area.

The Rio Grande, the only permanent stream traversing the area, has cut deep, steep-walled canyons across Mesa de Anguila (fig. 5), Mariscal Mountain (fig. 6), and the Sierra del Carmen (fig. 7). Terlingua Creek, an intermittent stream heading in the Jordan Gap quadrangle, drains most of the western Sunken Block area and enters the Rio Grande at the mouth of Santa Elena Canyon (fig. 5). Tornillo Creek, also intermittent, drains the area northeast and east of the Chisos Mountains and enters the Rio Grande west of the Sierra del Carmen (fig. 7). Both Terlingua and Tornillo Creeks in places have cut through the gravel that blankets much of the Sunken Block surface and the bedrock. Both streams mostly have broad, cobble-choked channels, but where they pass over resistant rocks they have developed steep-walled gorges, are largely clear of debris, and during most of the year have water flowing in a small current or standing in pools (fig. 33).

Relation of Topography to Structure and Lithology

Most of the high-standing areas are formed by resistant rocks, and the configuration of most topographic features reflects lithology and geologic structure. Anticlines are expressed by broad-topped ridges with hogbacks along the sides, tilted fault blocks by long serrate ridges or tilted mesas, and intrusions by oval domes. Some streams have cut strike valleys in the soft rocks, radial drainage is predominant on sides of domes, many of the highlands are flanked by pediments cut in soft rocks, and alluvial fans are conspicuous at the bases of escarpments.

Folded mountains.—Mariscal Mountain, in the south-central part of the Park (Pl. II; A–E, 19–22), is formed by a faulted anticline in hard, massive limestone, which is expressed as a long ridge whose shape conforms to the configuration of the fold (fig. 6). Alternating hard and soft layers that once covered the top of the fold now form hogbacks and strike valleys along its flanks. The Santiago Mountains are an intricately folded and faulted anticline, the highest part of which does not conform to the highest part of the structure. However, not all structurally high areas are topographically high, for at the Cow Heaven (Pl. II; B–G, 17–19; fig. 144) and San Vicente (Pl. II; G–J, 22–24) anticlines, soft shale on the crests of the folds is cut into a valley.

Fault block mountains and mesas.—The Sierra del Carmen is a bundle of linear ridges formed of tilted fault blocks of massive Cretaceous limestone. Most of the ridge tops are sharp, with dip slopes on the bedding surfaces of the tilted limestone, and fault scarps or fault-line scarps on the opposite side of the tilted ridge. The drainage, except for the Rio Grande and Heath Creek, parallels the faults, and the broader valleys are floored by rock debris from the adjacent highlands. Fault block mountains also occur southwest of the Chisos Mountains, which are capped by massive lava (fig. 8). Burro Mesa, an obsequent rift block mesa, is capped by massive Tertiary lava that covers the downthrown side of the Burro Mesa fault. The lava was left standing high above the surrounding area as erosion lowered the weaker Cretaceous rock from the upthrown side (fig. 150). Mesa de Anguila is a broader, more massive fault block, eroded from gently tilted strata. Its weak rocks are largely eroded from the mesa top, and the outline of the



Fig. 8. Lava-capped fault-block ridges southwest of the Chisos Mountains (Pl. II; F–H, 11–13). The Rio Grande and adjacent field and landing strip occupy the floor of a graben. Inked lines are the approximate location of faults.



Fig. 9. The Grapevine Hills northeast of the Chisos Mountains. The left-hand oval peak is near the center of the intrusion. Massive rock ledge in the foreground is a rim sill.

uplift is preserved by the hard massive limestone or by a sill in the Boquillas Formation.

Dome mountains.—Most of the dome-shaped uplifts are probably due to intrusions. One of the simpler of these is the Grapevine Hills (Pl. II; P–Q, 18–19), where intrusion arched the overlying sedimentary rocks and erosion stripped the cover from the top, leaving low, oval-shaped igneous peaks (fig. 9). The Christmas Mountains (Pl. II; Q–T, 10–13), mostly outside the mapped area, are due to intrusive doming and faulting (fig. 147). The high part of the uplift still retains its massive limestone and volcanic rock cover, but the softer formations eroded from the crest of the fold form hogbacks along the flanks; the intrusion is exposed along a fault on the western side. Dagger Mountain (Pl. II; N–Q, 3–4), an elongate faulted uplift, may be an intrusive dome in which the intrusion is not yet exposed.

The Chisos Mountains (Pl. II; D–M, 10–20), largest intrusive dome in the area, rise abruptly above a semiarid plain in the center of the Sunken Block. Their history includes multiple periods of deposition, uplift, erosion, and intrusive and extrusive activity. The rocks include minor amounts of Upper Cretaceous and Tertiary sedimentary strata, which are overlain by Upper Eocene and Oligocene clastic and pyroclastic rocks and massive lava, all of which have been domed by one or more intrusions. The northern part of the mountain area is a crescent-shaped intrusion (Ward-Pulliam Peaks) which forms the core of the uplift (Pl. II) and rises boldly on the west, north, and northeast sides. A dozen or more smaller intrusions, probably connected at depth to a much larger mass



Fig. 10. Rough terrain of the Chisos Mountains produced by erosion on rocks of unequal hardness. A, Ward Mountain. B, Vernon Bailey Peak. (Both are prominent elevations on the intrusion's rim.) C, The Window, a gorge incised across the intrusion. D, The Basin, a valley eroded from soft Tertiary and Cretaceous rocks. E, Casa Grande. F, Toll Mountain. G, Emory Peak. H, Lost Mine Peak. (Prominent topographic features eroded from hard lava.)

not yet exposed, are responsible for the local doming. As the Ward-Pulliam intrusion ascended, it elevated a roof pendant of soft Cretaceous and Tertiary formations that were eroded to form the Basin, a central depression (fig. 10).

Most streams in the Chisos Mountains head high on the outer mountain slopes and flow outward in a radial pattern. Some of the drainage follows the edges of the intrusions in broad channels. Streams that head on the intrusions mostly cut deep gorges and where they enter sedimentary rocks, descend in rapids or a vertical pour-off (intermittent waterfall). Oak Creek, one of the larger streams, has cut a narrow, steep-walled canyon across the Ward-Pulliam intrusion and descends in a pour-off at the sedimentary-igneous rock contact; as it worked headward, a precipitous escarpment was developed in the massive lava cap rock. Removal of the cap rock permitted erosion of the underlying weak rocks which were cut into the Basin, a broad, irregular depression, between the Ward-Pulliam intrusion and edge of the massive lava cap on Casa Grande, Toll, and Emory Peaks (fig. 11, in pocket).

The floor of the Basin was carved from soft sedimentary rocks that were deformed both before and during the intrusive doming. The Basin walls, 1,500 to 2,000 feet high, consist of the Ward-Pulliam intrusion on the west and north sides and the massive lavas in Casa Grande, Toll, and Emory Peaks on the remainder of the rim. Columns, spires, and buttresses are common along the rim, and almost everywhere the wall is conspicuously notched by intermittent streams that are working headward into either the intrusions or the lava-capped mesas.

The Basin is floored by bentonitic clay and soft sedimentary rocks mostly covered by boulders and gravel. During the occasional times when the clay becomes wet to some depths, both the boulders and clay move down the steep slopes. The boulders, as they move forward on the wet clay, form ridges which are preserved when forward motion ceases. Behind the ridges are shallow depressions that may hold water for a few days. The increased moisture encourages plant growth, so that most of the depressions have thick grass cover. The Boulder Meadows in the southern Basin area were formed by this process. The same features occur north of Pulliam Peak, west of Burro Mesa, at Sierra Aguja, and at Chilicotal Mountain.

PEDIMENT SLOPES

About 25 percent of the Park is covered by alluvial and colluvial deposits (Pl. II). These accumulations have not been studied in detail but can be broadly divided into (1) the old gravels, Pleistocene or pre-Pleistocene, that include consolidated high level terraces and valley fill deposits, high terrace gravel deposits, and pediment gravels (figs. 12 and 13); and (2) Recent gravel veneer on pediment gravel (fig. 14), stream-bed alluvium, and talus deposits (Pl. II).

Jenkins (1958) visited Big Bend National Park, briefly saw the Basin with its steep-faced lava escarpments, gravel-veneered bedrock ridges, and various slump features, and concluded that the area had been glaciated. The writer does not accept this interpretation for the origin of the Basin nor for any of the features therein; all features in the Basin are the result of weathering and erosion on rocks of variable hardness under climatic conditions similar to those at present (fig. 11).

Pediments and alluvial plains.—Pediments slope gently in all directions away from most of the highlands in the Park but are especially conspicuous around the Chisos Mountains, where the slope is at the rate of about 50 to 100 feet per mile toward the drainage channels. Udden (1907a, pp. 10–14) applied the term Graded Plain to these gravel-covered surfaces. The rock-cut surfaces bevel the edges of Gulfian and Tertiary formations, and the pediment slopes are controlled by temporary base levels of the drainage. On the south side of the Chisos Mountains, where the secondary drainage enters directly into the Rio Grande, the pediment surface is about



Fig. 12. Siltstone (Miocene and younger) interbedded with conglomerate and coarse sandstone about 3 miles northeast of Cerro Castellan (Pl. II; L, 25).



Fig. 13. View taken across the pediment slope at Punta de la Sierra, south of the Chisos Mountains; the bedrock is Gulfian clay and sandstone (Pl. II; D–E, 14–16).



Fig. 14. Alluvium about 5 miles northeast of Cerro Castellan (Pl. II; H, 12).

1,000 feet lower than on the north side where the tributaries flow to Terlingua Creek. Most pediments are being dissected, and terraces, observed on all sides of the Chisos Mountains, are the result of adjustment to changes in base levels.

The pediment deposits include silt, sand, gravel, and cobbles as much as a foot across and vary in degree of consolidation from weakly consolidated to well indurated. The deposits are as much as 100 to 150 feet thick (as determined by well records and in some canyons) but most of the gravel-debris blanket is only 20 to 30 feet thick and is generally less than 10 feet thick near its outer margin.

The upper border of the pediment gravel forms a crenulate line around the Chisos Mountains and is trenched by arroyos that radiate from them. The arroyos are deepest close to the base of the escarpment and fade out in the outwash blanket and within a mile of the base of the mountains. Some of the arroyos are subparallel for 10 or more miles, such as Glenn Springs and Juniper Draws (Pl. II). The headwaters of these two channels are less than half a mile apart, and nowhere are they more than 1½ miles apart until they finally join before reaching the Rio Grande. All of the arroyos are V-shaped in their upper courses, but the lower parts of the longest arroyos commonly have meandering, boulder-choked floors 200 to 300 yards wide.

Stability of the pediment slope surrounding the Chisos Mountains appears to be due, at least in part, to achievement of near equilibrium. The streams in each arroyo maintain a grade depending upon the coarseness and quantity of its load; close to the mountain the load is so great that most streams are aggrading. Arroyos cut during one period of run-off may be filled with debris during the next rain. Commonly, a ridge of cobbles and boulders is left in or alongside the old channel. Jenkins (1958) believed that these mud flow levees are moraines. South of Punta de la Sierra (Pl. II; E, 15), the arroyos have been

filled to a such an extent that the deposit forms an alluvial plain (fig. 13).

Where the load of debris is less than runoff can remove, the surface is eroded. Erosion is most conspicuous in the high areas near the mountain front, either during torrential rainfall or when successive rains remove the rock debris from the highlands faster than it accumulates. The length of the arroyos depends upon the surface slope, for as the running water reaches the more gentle grades, deposition begins and the water spreads—forming sheetfloods.

Sheetfloods are important in maintaining the uniform slope of the pediments. During torrential rains, the arroyos near the foot of the mountain become choked with rock debris; the boulders bounce like corks, and the impact between boulders is clearly audible (fig. 4). As the water reaches the more gentle slopes, the velocity decreases, deposition begins, and the water divides into streamlets which move back and forth on the aggrading surface in a braided pattern. Downslope from the braided zone, the water overflows the banks to form a sheetflood. The sheetflooded areas extend from a few hundred feet on one or both sides of the arroyo to half a mile or more, depending upon the local topography and the amount and rapidity of the rainfall (fig. 13). Many of the sheetfloods from adjacent arroyos coalesce and blanket extensive areas with gravel.

The debris apron surrounding the Chisos Mountains probably was formerly more extensive than now, and despite brief rebuilding periods, the pediment gravel deposit seems to be slowly dissected, especially along its outer margin. Probably the history of the present pediment gravel is only the reenactment of deposition and destruction of similar deposits formed when the Chisos Mountains were higher. A remnant of an older accumulation forms the large gravel mass that extends from near Hannold Hill southeastward to beyond Dugout Wells (Pl. II; L–P, 21–24); the gravel that caps Burro Mesa probably had similar history.

ORIGIN OF DRAINAGE COURSES

River canyons.—The principal canyons in Big Bend National Park are (1) Santa Elena, (2) Mariscal, and (3) Boquillas, all cut by the Rio Grande (Pl. II). Santa Elena is incised across Mesa de Anguila, a tilted fault block; Mariscal crosses Mariscal Mountain, a faulted anticline; and the Boquillas Canyon is incised across several fault-block mountains composing the Sierra del Carmen. The canyon depths are similar, about 1,600 feet; the canyon lengths are variable, depending on the width of the highland crossed. Mariscal Canyon is 6 to 7 miles long; Santa Elena is 15 to 18 miles long, of which 7 to 8 miles is boxlike with vertical walls; and Boquillas Canyon is about 25 miles long.

Udden (1907a, pp. 15–16) believed the Rio Grande is antecedent and developed its course before the present structures were formed. If so, the course of the Rio Grande was probably established before the Laramide orogeny, as the oldest structures crossed by the river in the Mariscal Mountain, south of the Chisos Mountains, are Laramide. Udden thought that Terlingua Creek was adjusted to the larger geologic structures. He noted that Tornillo Creek follows a line of soft outcrops along much of its course but near its mouth cuts a short canyon (Banta Shut-In) through an uplift and there has antecedent characteristics. He believed that the west tributaries of Maravillas Creek (Nine Point Draw) where they cross the Santiago—Sierra del Carmen ranges are antecedent. He reported that ". . . in general, the drainage of the Chisos country is in a stage of adjustment to geologic structure. Nearly all of the smaller streams are through this stage, the larger creeks are still in it, and the Rio Grande has hardly yet entered upon it."

Baker (1934) believed that the lowland that now lies between the Santiago—Sierra del Carmen ranges on the east and Mesa de Anguila on the west was filled by a lake, the surface of which may have reached an elevation of at least 4,000 feet, a sufficient height to have covered Mesa de Anguila,

Mariscal Mountain, and the surrounding areas, leaving only the highest peaks in the Chisos and Sierra del Carmen Mountains standing as islands above its surface (Pl. II). He further suggested that the present course of the Rio Grande might result from either (1) superimposition from ancient lake deposits which entirely buried some of the uplifts, so that when erosion reached the base of the lake beds, the river cut downward into the massive limestone, or (2) the original Rio Grande channel was underground and the canyons were formed by collapse of the rocks of the solution channels.

P. B. King (1935, pp. 256–261) proposed that most of the normal fault blocks in Trans-Pecos Texas were displaced during the Miocene and Pliocene and that the intermontane basins were then filled with debris. He supposed that toward the end of this epoch, the surface of the fill reached a height that permitted several basins to become more or less connected. The Rio Grande may not have taken its present course across New Mexico and west Texas until long after the epoch of block faulting and basin filling, although an ancient stream may have existed in central New Mexico and, for a time, emptied southwestward into the basin of Laguna Guzman in northern Chihuahua west of El Paso, Texas. King suggested that the lower course of the Rio Grande, between the Sierra del Carmen and the Gulf of Mexico, may have existed prior to the period of block faulting and basin fill in the Trans-Pecos area and that this ancestral stream made important contributions of sediments to Tertiary formations on the Texas Gulf Coast as early as Eocene.

According to King's hypothesis, the intermontane basins in Trans-Pecos Texas were not connected by a large stream until long after the epoch of valley fill. The valley-fill material was derived from the adjacent mountains and was deposited in shallow lakes or playas. By the end of the basin-filling epoch, the surfaces in the intermontane basins were built to such a height and the pediment cut so far into adjacent mountain slopes that some valleys were more or less connected to other basins at the low points in the encircling mountain barrier. As the valleys filled, the water sought the lowest outlet and overflowed into a lower basin. The fill and overflow process was cumulative and in time drainage was established across the fault block mountain belt in Trans-Pecos Texas. The establishment of the through-flow drainage of the Rio Grande from the western slope of the Rocky Mountains in Colorado to the Gulf of Mexico may have been aided by later uplift.

The original thickness of the basin deposits in the Big Bend country is speculative, but undoubtedly the fill covered many of the lower ridges and mesas. In the Rio Grande valley, near Presidio, Texas, drillers' logs indicate a thickness of about 2,000 feet for existing bolson deposits. Remnants of bolson deposits high on the flank of the Chinati Mountains suggest that as much as 1,500 feet of material may have been removed along the river valley. Southeastward, in the Park, the thickness of valley fill deposits is much less, but if they blanketed the lowland to heights as great as those of isolated outcrops on the flanks of the Chisos Mountains and Sierra del Carmen, the original thickness was impressive. They probably covered the Mesa de Anguila—Sierra Ponce fault block and at least the northern end of Mariscal Mountain and Sierra San Vicente (Pl. II). The distribution of valley fill in the Sierra del Carmen suggests that only the ridgetops may have stood above the debris blanket.

Structural features influenced the final location of the river channel in some places. At Colorado Canyon, in southeastern Presidio County and northwest of the Park, the Rio Grande has trenched a canyon that generally parallels the lowest segment in a compound graben. Farther southeast, along the northwestern half of Mesa de Anguila, the river channel parallels the downthrown side of the major faults. Farther downstream, the river cuts diagonally across the mesa, and the joint system in massive Cretaceous limestone has partly controlled the

position and direction of its course. For about 15 miles southeast of Mesa de Anguila, the river valley follows the downthrown side of the Terlingua fault, and the blocks southwest of the Chisos Mountains are upthrown away from the river (Pl. II). Mariscal Mountain was probably covered by the valley fill, and the canyon is incised across most of the uplift at right angles to the axis of the structure. East of Mariscal Mountain, the Rio Grande cuts diagonally across the floor of the Solis Graben and swings north around the plunging end of the highest part of the Sierra San Vicente uplift. The eastern course of the river continues across the axis of most folds and fault blocks and crosses the Sierra del Carmen along a route that is structurally lower than the mountain ridges either north or south (Pl. II).

The subsequent history of the Rio Grande is one of downcutting. The canyons that were cut across the formerly buried ridges have been deepened; most of the valley fill deposits have been removed; large quantities of the weak rocks in the structurally low areas, like the Sunken Block between Mesa de Anguila and the Sierra del Carmen, have been carried away, leaving knots of hard rock like the Chisos Mountains standing in bold relief; and the scarps along some of the fault blocks were deeply eroded. Some fault scarps are straight, fresh escarpments without extensive erosion, and some of the valley fill deposits have been tilted and probably faulted. The Terlingua fault scarp at the mouth of Santa Elena Canyon is one of the features that appears young. This suggests that Mesa de Anguila was either only recently uncovered, or that there was renewed uplift along the Terlingua fault. The youthful appearance of the scarp has led some geologists to conclude that the Rio Grande is antecedent to Mesa de Anguila and other uplifts in the Big Bend, but the alternate hypothesis answers more of the problems related to the Rio Grande history.

STRATIGRAPHY

Ross A. Maxwell and Roy T. Hazzard

General Outline

A wide variety of rocks are exposed in the Big Bend region. Although Cretaceous and Tertiary formations cover most of the area, the span of geologic time represented by rocks extends from early Paleozoic to Recent (table 1). Some of the established stratigraphic nomenclature from the Marathon and central Texas areas has been used, but in most cases, new names are introduced to designate the lithostratigraphic units as they occur in the Park. Paleozoic rocks crop out prominently in the Marathon Basin and are also exposed in Persimmon Gap, the Solitario, and the Shafter—Pinto Canyon areas; metamorphic rocks, probably of Paleozoic age, crop out near Boquillas, Coahuila, Mexico. Comanchean rocks mainly are massive limestones with minor amounts of nodular, marly limestone, marl, and shale. Gulfian rocks are flaggy, argillaceous limestone, chalk, marl, clay, bentonitic clay, and sandstone. Tertiary formations are sandstone, clay, pyroclastic rocks, tuffaceous rocks, and lava. Intrusive igneous rocks include numerous dikes, sills, large irregular tabular bodies, and several conspicuous bosslike masses. Much of the bedrock surface is concealed by a mantle of alluvium or colluvium that is of Miocene to Recent age.

The rocks crop out in a variety of attitudes and locally are completely deformed. Horizontal strata are rare but anticlines, synclines, quaquaversal structures, and tilted fault blocks are common. Major folds and faults trend northwest and extend beyond the Park boundaries. Erosion has produced striking outcrop patterns (Pl. II).

Many of the stratified rocks contain fossils that locally are abundant. Marine invertebrates occur in Comanchean and early Gulfian formations. Dinosaur bones and teeth, turtle and crocodile remains, shark teeth, and fossil wood occur in the terrestrial deposits of the upper Gulfian formations. Mammalian remains are present but not abundant in some of the Tertiary formations. Some volcanic rocks have distinctive mineralogy or characteristic mineral assemblages; these have been useful in correlation.

The total exposed thickness of the sedimentary and volcanic rocks is about 13,800 feet, of which the Paleozoic comprises about 1,400 feet, the Comanchean, 2,000 feet, the Gulfian, 3,100 feet, the Paleocene—Lower-Middle Eocene, 2,800 feet, and the Upper Eocene—Oligocene volcanics, 4,500 feet. Post-Oligocene alluvial and colluvial deposits are normally thin, but in some valleys they are up to about 520 feet thick. General descriptions of the stratified rocks are given in the table of geologic formations (table 1, p. 6).

Paleozoic, Ordovician System

Undifferentiated Limestone and Shale

A few miles southeast of Persimmon Gap (center of Pl. IV) a slice of Paleozoic rock is thrust upon Santa Elena Limestone and is in turn partly overridden by Del Carmen Limestone. The Paleozoic beds are brownish and dark bluish, flaggy limestone with shale partings, which are crumpled, fractured, and considerably altered. One part is predominantly crumpled brown and dark-green shale containing only a few lime-

stone layers. Fossils were not found, but the lithology resembles the Marathon Limestone and Alsate Shale in the Marathon Basin. Less than 100 feet of these beds is probably exposed.

Maravillas Chert

GENERAL FEATURES

The Maravillas Chert was named by Baker and Bowman (1917, p. 87) for rocks exposed in Maravillas Gap on the old Marathon-Terlingua road southwest of Marathon. In the Marathon Basin the formation crops out on the lower and inner slopes of the novaculite ridges and adjoins the valley cut on the underlying Woods Hollow Shale.

In the Marathon area the Maravillas Chert consists of black chert layers alternating with black petroliferous limestone layers with pinkish-weathering shale partings. Chert dominates over limestone in the upper 150 to 200 feet. P. B. King (1937, p. 36) reported that the Maravillas is 100 to 400 feet thick in the Marathon Basin. According to J. L. Wilson (1954a, p. 2462), the Maravillas is 154 feet thick in the Solitario.

LOCAL FEATURES

Persimmon Gap area.—A short distance southeast of the Persimmon Gap benchmark (elev. 2,971 feet) is a dark-brown hill consisting mostly of Maravillas Chert (Pl. IV). The chert is involved in both pre-Cretaceous and post-Cretaceous thrust faulting and is now exposed in the center of the Santiago Mountains structure. The best exposure of the upper part of the formation may be reached by walking about three-quarters of a mile east from the Park road to a point midway between the benchmark and the Park ranger station. East of a thrust fault, on which a slice of Maravillas overrode Comanchean (Glen Rose) limestone, the top of the Maravillas is exposed up a steep-walled arroyo along the southern flank of the brown hill, overlain by three units of the Caballos Novaculite.

Much of the Maravillas at this locality is covered with loose rock debris, but there appears to be a predominance of chert in the upper part of the exposure and an increase in the amount of limestone downward. The top bed of the Maravillas, about 1 foot thick, is jointed, fractured, gray chert. Below the top chert bed is 5 feet of hard, gray, pink, orange, and brown shale. From this shale a few poorly preserved graptolites have been collected. The next lower 35 feet are predominantly black chert layers from 2 to 8 inches thick (average thickness 4 inches) with brown shale partings separating the chert bands. The chert beds are closely jointed and break into rectangular blocks. In the remainder of the section dark chert beds with shale partings are dominant, but there are some beds of black or dark-brown limestone, as well as a few thin conglomerate lenses with chert and limestone pebbles.

The formation is intricately deformed and involved in both pre-Cretaceous and post-Cretaceous thrusting. Probably the lower part of the formation was sliced off as it overrode the Tesnus Formation on which it now rests. Because of the complex structure and deformation, thickness measurements are not reliable but probably about 200 feet of the beds are exposed.

Some 250 yards southeast of the graptolite locality, up the slope extending toward the crest of the Comanchean fold, is a second thrust slice of Maravillas (Pl. IV). The rocks in this exposure have also been thrust over the Tesnus and are overlain by Comanchean (Glen Rose). The strata are predominantly chert, but a few limestone beds are present. The exposed section does not exceed 40 feet. No fossils were found. Lithologically, the beds are most like the upper strata exposed in the arroyo southeast of the dark-brown hill.

About 2,000 feet east-northeast of the Persimmon Gap benchmark, 25 feet of Maravillas beds are exposed in the sides of an arroyo. The beds appear to be part of a Maravillas slice that rode northwest on a thrust; they are exposed only where erosion has cut through the Glen Rose cover (Pl.

IV). No fossils were found and chert dominates over limestone.

Southwest of Persimmon Gap, at the apex of a triangle in which lines drawn to the benchmark and the ranger station represent the legs, is another Maravillas exposure (Pl. IV). Here again the strata are involved in a thrust slice where the Maravillas overrode Glen Rose. The cherty rocks are about 10 to 15 feet thick, and no fossils were seen.

Dog Canyon area.—About 2,000 to 3,000 feet southeast of the mouth of Dog Canyon are two isolated exposures of Maravillas Chert (Pl. IV), thrust upon the Glen Rose. The larger mass is predominantly dark-brown and blackish chert, but a few limestone beds alternate with the chert. No fossils have been found. The beds are moderately deformed, and one promontory, from a distance, looks more like jointed igneous rock than sedimentary rock. Because of the deformation, measurement of a detailed section is impossible, but the vertical exposure is about 75 feet thick.

More than 800 feet southeast of the mouth of the canyon is a small area of Maravillas-like rock thrust upon the Sue Peaks Formation. It also is predominantly dark chert and severely deformed by the thrusting. No fossils were found, but lithologically it is similar to the Maravillas in other areas.

FOSSILS AND AGE

Only graptolites were found in the Maravillas Formation in Big Bend National Park. These came from shale beds 1 to 6 feet below the top of the formation at the exposure about three-quarters of a mile southeast of Persimmon Gap. As they are poorly preserved specimens, identification was not attempted. The writers believe, however, that the Persimmon Gap—Dog Canyon exposures are equivalent to some part of the Maravillas in the Marathon Basin, probably the upper strata, and are Late Ordovician in age.

Devonian and Mississippian Systems

Caballos Novaculite

GENERAL FEATURES

Udden et al. (1916, pp. 39–41) named a Caballos Novaculite and an overlying Santiago Chert in the Marathon area. Baker and Bowman (1917, pp. 93–94) rejected Santiago Chert, because their later field work showed that it was indivisible from the Caballos and intergraded with it. P. B. King (1937, pp. 47–55) confirmed Baker and Bowman, finding that the Caballos was divisible into five members, two of novaculite, three of chert. He also showed that the upper novaculite, which makes the main novaculite mass on Horse Mountain the type locality of the Caballos, is equivalent to and pinches out into the alleged Santiago Chert of 1916; the latter constitutes the middle and upper chert members of the 1937 terminology. King further observed a persistent conglomerate at the base of the middle chert, suggesting a possible significant hiatus at this level in the Caballos. Berry and Neilsen (1958) recognized the same units as King and emphasized the probable hiatus at the base of the middle chert, which to them suggested two depositional units in the Caballos. They termed the lower one Caballos, the upper Santiago. King (*in* Flawn et al., 1961, p. 179) strongly dissented, because this proposal would drastically restrict the scope of Caballos from its long-accepted usage. He emphasized the identity of the Caballos to the Arkansas Novaculite, concluding that both will eventually be classed as groups, made up of component formations. The rocks preserved in the Park area correspond to the middle and upper chert members and the upper novaculite member in the Marathon Basin. These units are the part that has been called Santiago Chert by Berry and Neilsen (1958).

LOCAL FEATURES

Persimmon Gap.—In the arroyo on the southeast flank of the brown Maravillas hill near Persimmon Gap, the Maravillas is overlain by Caballos Novaculite, of which three units are exposed (Pl. IV). These are, in ascending order: (1) reddish shale and chert (Wilson's (1954a, pp. 2462–2463) Persimmon Gap Shale), (2) novaculite (King's (1937, p. 47) upper novaculite member), and (3) chert (King's (1937, p. 47) upper chert member).

The red shale-chert member is 45 feet thick, of which the lower 30 feet is predominantly greenish, gray, drab, siliceous shale that weathers to pink and reddish brown. Freshly broken surfaces are greenish but the color fades on weathered outcrops. The upper one-third of the member is a well-jointed green, brown, and black chert in beds 2 to 3 inches thick interbedded with greenish shale that weathers red.

The middle novaculite member includes 30 feet of massive, light-gray or gray-white, highly fractured novaculite with vitreous texture. The novaculite normally forms a prominent ledge in contrast to the dark shale and chert above and below.

The upper chert member has interbedded layers of black, brown, green, and gray chert, 1 to 4 inches thick, and thin bands of brown siliceous shale. Total thickness is about 40 feet.

FOSSILS AND AGE

No fossils were collected by the writers from these rock units in Big Bend National Park. The correlation at Persimmon Gap is based on lithology and stratigraphic and structural relationships of the novaculite-chert-shale beds with the adjacent formations. King (1937, p. 52) reported that the Caballos Novaculite contains a few fossils but none gives a definite indication of age. He listed linguloid brachiopods, conodonts, and radiolaria from thin sections of chert and suggested a Devonian(?) age. Aberdeen (1940, pp. 127–137) described 24 species of radiolaria from the lower red shale-chert member and assigned a late Devonian age. Graves (1952) interpreted conodonts collected from the upper chert member as Late Devonian. The upper part of the equivalent Arkansas novaculite is of proven Mississippian age (P. B. King, personal communication, September 23, 1963).

Mississippian and Pennsylvanian Systems

Tesnus Formation

GENERAL FEATURES

The Tesnus Formation was named by Udden et al. (1916, p. 45), and was more fully defined by Baker and Bowman (1917, pp. 101–105), from exposures near Tesnus Station on the Southern Pacific Railroad about 22 miles southeast of Marathon. King (1937, pp. 55–63) described the formation in more detail and showed that it consists largely of sandstone and shale and ranges in thickness from more than 6,500 feet in the southeastern part of the Marathon Basin to about 300 feet in the northwestern part of the basin. In the Tesnus-Haymond area (east-central Marathon Basin), where the formation is thick, a basal shaly member can be differentiated from the dominant sandstone of the upper three-fourths of the formation. This was called the Rough Creek Shale Member (Baker and Bowman, 1917, pp. 101–103) from exposures along Rough Creek (southeastern part of Marathon Basin), but this name is preempted by a Pennsylvanian unit in central Texas. The top 300 to 400 feet of beds near Tesnus Station are black shale with subordinate sandstone. The upper sandstone unit in places (Hells Half Acre and Devils Backbone) contains beds like the Jackfork Sandstone of the Ouachita Mountains (King, 1937, p. 57). On the northwest side of the Marathon Basin,

where the Tesnus is very thin, it is predominantly shale that probably correlated with the upper shale unit near Tesnus Station.

LOCAL FEATURES

Persimmon Gap.—The Tesnus is exposed in Persimmon Gap, near the entrance to Big Bend National Park. The largest outcrop occupies an irregularly elliptical area surrounding the benchmark (elev. 2,971 feet) and extends beyond the area mapped (Pl. IV). It is dark-gray, brown, and black, hard, brittle shale with a few seams and irregular veinlets of white quartz. Shale is predominant, but there are beds throughout the exposures of fine-grained, rusty brown and blue-black sandstone, and the top of the exposure is predominantly sandstone. The basal contact is marked by a brown siliceous conglomerate, 3 to 24 inches thick, in which angular pebbles of dark chert and gray-white novaculite are prominent. The conglomerate is best seen along the Caballos-Tesnus contact about 3,000 feet southeast of the benchmark (elev. 2,971 feet). It is also exposed in a small area about 2,000 feet west of the same benchmark. The top of the sequence is commonly faulted against Cretaceous formations, but where not faulted, a brownish-red conglomerate forms the base of the Cretaceous.

Four small Tesnus rock exposures crop out west of the Park road between the Persimmon Gap benchmark and the Park ranger station, and a fifth and larger exposure off the map (Pl. IV) occurs along the southwest flank of the Santiago Mountains about 1¼ miles west of the Park road. Rocks in all five areas are sliced by thrust faults.

Southeast of the Persimmon Gap benchmark (about 1 to 2 miles) are two other Tesnus exposures (Pl. IV). The Glen Rose Formation, locally with conglomerate at the base, overlaps the Tesnus on the southwest, and normal faults, partially obscured by alluvium, bring mid-Glen Rose rocks in contact with the Tesnus on the northeast.

Dog Canyon area.—About 1¼ miles southeast of the mouth of Dog Canyon is a thin slice of rocks that are probably Tesnus (Pl. II). This formation is bounded by faults except on its southwest side where beds of the Glen Rose are in depositional contact with the older strata.

Sections of Tesnus were not measured in Big Bend National Park. The rocks in all exposures are faulted and otherwise deformed, but the thickness probably does not exceed 500 feet.

FOSSILS AND AGE

The Tesnus in the Marathon Basin has yielded a few plant fossils which were studied by David White (King, 1937, p. 61), who determined them to be of Pennsylvanian age and younger than the flora of the Jackfork Sandstone in Oklahoma. The fossil plants came from the north end of West Bourland Mountain (northwestern part of Marathon Basin) about 400 feet below the top of the Tesnus. Bruce Harlton (King, 1937, p. 61) collected foraminifera from near the top of the Tesnus about 18 miles east of Marathon and concluded that they are lowermost Pennsylvanian. Sponge spicules are also known but age determinations have not been attempted.

P. B. King (1930, p. 36) pointed out that although the fossils indicate a Pennsylvanian age for the upper part of the Tesnus, the age of the several thousand feet of strata below the fossils has not been determined and the lower part may be Mississippian. He (1937, p. 85) believed that the Tesnus correlates with some part of the Stanley, Jackfork, and Springer clastic series in Oklahoma and Arkansas.

Jones (1953, p. 22) assumed that the fossil plants studied by White came from the lower part of the upper Tesnus and were of Morrowan age; he also considered the Tesnus below the fossil occurrences as correlative with some part of the Jackfork. He suggested that the basal Tesnus (Baker and Bowman's "Rough Creek" Shale) may be comparable to Stanley Shale (early Mississippian), from which

Meramecian conodonts have been identified (Jones, 1953, p. 19).

Cline (1956a, p. 428) concluded that the so-called Mississippian Caney boulders of the Johns Valley Shale in Johns Valley, Oklahoma, are sideritic concretions within the lower part of the Johns Valley Shale and correlated the lower part of the Johns Valley with the Caney. As Johns Valley overlies the Jackfork, the latter must be Mississippian or older. Cline (1956b, p. 103) concluded that both the Stanley and Jackfork are Mississippian. Hass (1956) regarded Stanley conodonts as early or middle (Meramecian) Mississippian age. Elias (1959, p. 158) reported that a small but stratigraphically very important collection of conodonts from the lower Stanley provides strong evidence in favor of an early instead of median or late Mississippian age for the lower Stanley. Branson (1959) assigned a Mississippian age to both Stanley and Jackfork.

No fossils were collected from the Tesnus in Big Bend National Park. The lithology of these beds is most akin to part of the Tesnus in the Rough Creek area described by King (1937, p. 57). This part is probably basal Tesnus and older than beds from which White (King, 1937, p. 57) identified a Pennsylvanian flora and Harlton (King, 1937, p. 57) collected Pennsylvanian foraminifera. Possibly at least part of the Tesnus in Persimmon Gap is Mississippian.

Cretaceous System

Cretaceous rocks form the inner periphery of the Gulf Coastal Plain from Florida westward across Texas, and they also extend northward from Texas across the Great Plains and Rocky Mountain states into Canada and southward into Mexico. Where Cretaceous rocks are not exposed at the surface, deep wells prove that they lie beneath. Over this wide area, these rocks change much in facies and thickness.

In Big Bend National Park and elsewhere in west Texas are great thicknesses of marine and nonmarine Cretaceous rocks, most of which are well exposed. Many geologists have contributed to the understanding of Cretaceous stratigraphy in Texas, including R. T. Hill, T. W. Vaughan, J. A. Taff, F. W. Cragin, J. A. Udden, Emil Böse, Gayle Scott, W. S. Adkins, and L. W. Stephenson.

The regional correlation chart of Cretaceous formations (table 2, pp. 30–31) is compiled from published literature and presents one of several possible correlations for the Cretaceous sequence in Big Bend National Park. It especially reflects the concepts of W. S. Adkins for the Comanchean and Adkins' and L. W. Stephenson's ideas of the Gulfian.

TRINITY GROUP

Glen Rose Limestone

The Glen Rose was named by R. T. Hill (1891, pp. 504–507) from rocks along the Paluxy River near Glen Rose (Somervell County), Texas. The Glen Rose is primarily a limestone formation but is in part clay and sandstone and was deposited in a transgressing sea whose margin moved northward, depositing sandy or conglomeratic layers in a near-shore facies. In west Texas the Glen Rose has irregular thicknesses and distribution. The northern sandy marginal facies forms a belt extending from the Marathon Basin northward through the Fort Stockton area and westward toward El Paso. South of that belt, the Glen Rose thickens, the lower part being sandy and the upper part being limestone and marl.

The northward thinning and pinch-out of the Glen Rose can be observed on the es-

carpments around the Marathon Basin. At Gap Tank on the east the Glen Rose ends abruptly. In the Del Norte Mountains the northernmost Glen Rose is almost due west of Marathon. The Glen Rose is absent in the Glass Mountains, where Fredericksburg rocks lie on the Paleozoic, but it may appear in places farther north, as several hundred feet of Glen Rose is reported in wells near Hovey, Texas. South of the pinch-out in the northern Marathon Basin, the Glen Rose thickens rapidly to 200 to 300 feet 8 or 10 miles south of Gap Tank, 500 feet on the south rim of the Basin, and 550 feet near Del Norte Gap. Southward the Glen Rose is exposed in the Santiago Mountains; it fails to emerge in the northern Sierra del Carmen but is again exposed in the southern Sierra del Carmen and in Mexico.

Local Features

Persimmon Gap.—In the area surrounding Persimmon Gap a sequence of Glen Rose lies with basal sandstone and conglomerate upon the Tesnus (Pl. IV). The basal bed is brick-red conglomerate, 8 to 10 feet thick, with well-rounded chert and novaculite pebbles up to 4 inches across (fig. 15). The conglomerate is overlain by 3 to 4 feet of red, coarse-grained sandstone; still higher is a second bed of gray conglomerate, about 10 feet thick, also containing chert and novaculite pebbles. This is followed by 35 feet of reddish clay alternating with sandstone (Pl. VI, no. 10). No igneous pebbles were found in the conglomerate. The red clastic beds are readily seen from the Persimmon Gap benchmark (elev. 2,971 feet), where they border the hills of Paleozoic rock and can be traced a mile or more northwestward in the foothills along the northeast side of the Santiago Mountains.

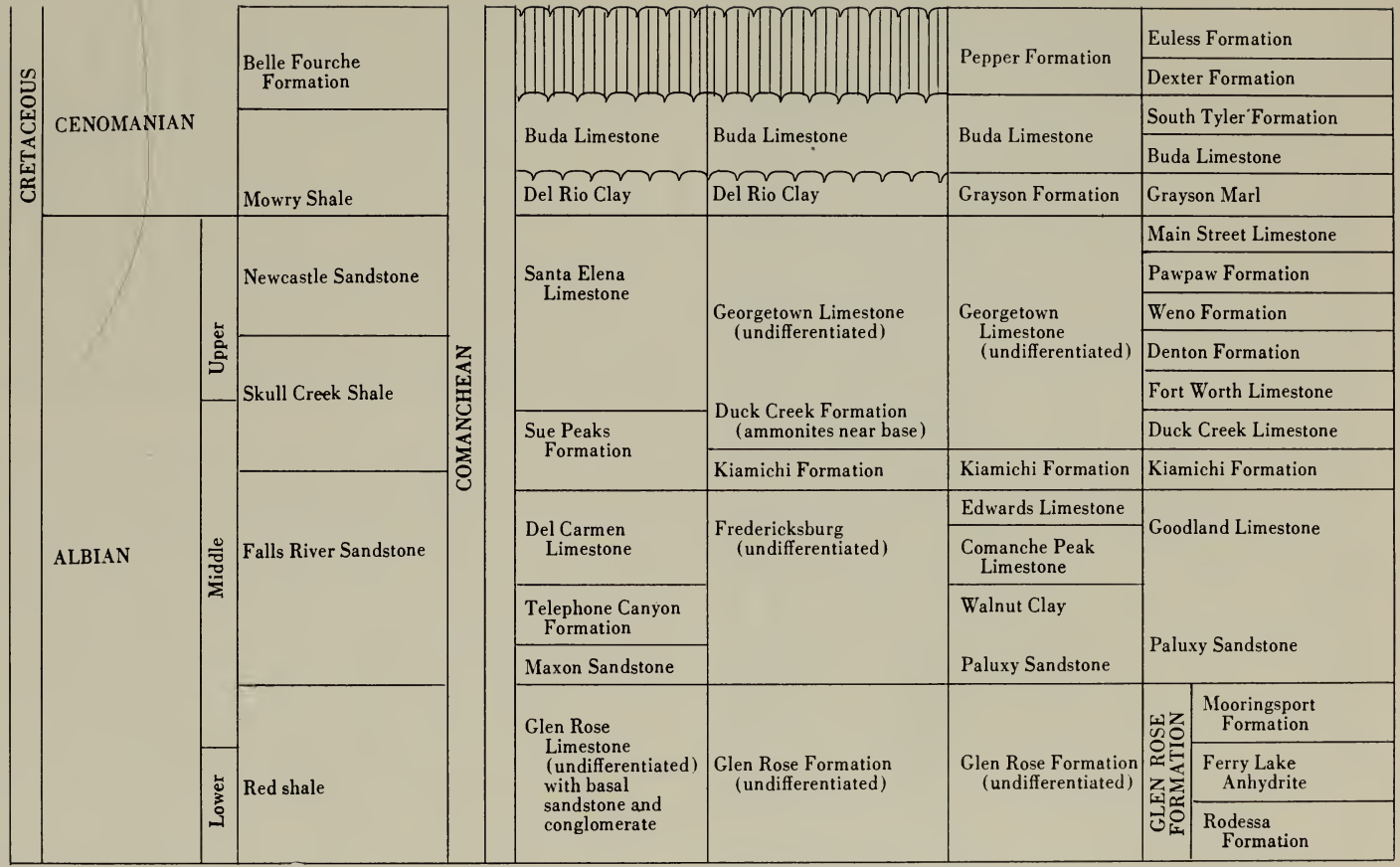
Above the clastic rocks is about 35 feet of gray and brown marl and brownish, nodular, marly limestone containing *Exogyra quitmanensis*, especially in a 5-foot ledge of coquina 15 feet above the base (Pl. VI, no. 10). The ledge also contains



Fig. 15. Conglomerate at the base of the Glen Rose near Persimmon Gap.

TABLE 2.—Correlation table for Cretaceous formations.

SYSTEM	EUROPEAN STAGES	REFERENCE SEQUENCE FOR WESTERN INTERIOR	SERIES	GROUP	BIG BEND NATIONAL PARK AREA	RIO GRANDE EMBAYMENT OF SOUTHWEST TEXAS (Surface and Subsurface)	CENTRAL TEXAS	NORTHEAST TEXAS (Surface and Subsurface)
	MAESTRICHTIAN	Fox Hills Sandstone	GULFIAN	TORNILLO	Javelina Formation Contains dinosaur bones, silicified wood, and coal beds	Escondido Formation	Kemp Clay	Kemp Clay
						Olmos Formation	Corsicana Marl	Corsicana Marl
						Upper San Miguel Formation		Nacatoch Sandstone
		Pierre Shale			AGUJA FORMATION: Continental sandstone and shale with Upper Campanian age dinosaur bones	Lower San Miguel Formation	Bergstrom Formation	Neylandville Marl
	CAMPANIAN					Anacacho Limestone	Pecan Gap Chalk and Clay	Pecan Gap Chalk
								Wolfe City Sandstone
					Marine sandstone and shale with *Exogyra ponderosa* and *Texanites* sp.	Upon Clay (with *Exogyra ponderosa* and *Texanites* sp.)	Sprinkle Formation	Lower Taylor Formation
		Eagle Sandstone		TERLINGUA		Burditt Chalk	Burditt Chalk	Gober Chalk
		Telephone Creek Formation			Pen Formation (with *Exogyra ponderosa*)	Austin Chalk (with *Exogyra ponderosa*)	Dessau Chalk (with *Exogyra ponderosa*)	Brownstown Marl
	SANTONIAN	Niobrara Formation			BOQUILLAS FORMATION: San Vicente Member (without *Exogyra ponderosa*)	Austin Chalk (without *Exogyra ponderosa*)	Jonah Limestone	Blossom Sandstone
							Vinson Chalk	Bonham Clay
	CONIACIAN						Atco Chalk	Ector Chalk
		Carlisle Shale			Ernst Member	Eagle Ford Formation	Eagle Ford Formation	Eagle Ford Formation
	TURONIAN							Lewisville Formation (volcanics)
		Greenhorn Limestone						


CRETACEOUS
CENOMANIAN
ALBIAN
Upper
Middle
Lower
COMANCHEAN
Belle Fourche Formation
Mowry Shale
Newcastle Sandstone
Skull Creek Shale
Falls River Sandstone
Red shale
Buda Limestone
Del Rio Clay
Santa Elena Limestone
Sue Peaks Formation
Del Carmen Limestone
Telephone Canyon Formation
Maxon Sandstone
Glen Rose Limestone (undifferentiated) with basal sandstone and conglomerate
Buda Limestone
Del Rio Clay
Georgetown Limestone (undifferentiated)
Duck Creek Formation (ammonites near base)
Kiamichi Formation
Fredericksburg (undifferentiated)
Glen Rose Formation (undifferentiated)
Pepper Formation
Buda Limestone
Grayson Formation
Georgetown Limestone (undifferentiated)
Edwards Limestone
Comanche Peak Limestone
Walnut Clay
Paluxy Sandstone
Kiamichi Formation
Glen Rose Formation (undifferentiated)
Euless Formation
Dexter Formation
South Tyler Formation
Buda Limestone
Grayson Marl
Main Street Limestone
Pawpaw Formation
Weno Formation
Denton Formation
Fort Worth Limestone
Duck Creek Limestone
Kiamichi Formation
Goodland Limestone
Paluxy Sandstone
GLEN ROSE FORMATION
Mooringsport Formation
Ferry Lake Anhydrite
Rodessa Formation

ammonite fragments as well as pelecypods, gastropods, and echinoids. The coquina ledge is a useful tool for mapping the complexly faulted structure of the southern Santiago Mountains. The higher part of the Glen Rose is blue, bluish-gray-brown and reddish-brown, hard, fine- to medium-grained limestone in 1- to 10-foot beds, alternating with yellowish-gray, buff, and reddish-brown marl so as to form a terrace topography. Near Persimmon Gap, all the Glen Rose is faulted and the top is not exposed. The full thickness of the formation is thus undeterminable but is at least 335 feet thick.

Love ranch.—The Love (formerly Purnell) ranch joins the Park on the northeast side of the Santiago Mountains. A section (Pl. VI, no. 9) was measured near a butte crossed by structure section J–J′ (Pl. V), about 1½ miles southeast of Persimmon Gap. Here the base of the Glen Rose is 10 feet of red conglomerate sandstone with chert pebbles (probably Maravillas) which is overlain by 12 to 15 feet of white, coarse-grained sandstone. These are followed by 38 feet of yellowish-gray, buff, and brownish marl and soft marly limestone containing *E. quitmanensis* which is not so numerous as in the Persimmon Gap area and does not form coquina ledges.

Above the *Exogyra quitmanensis* beds is about 90 feet of gray and brownish, fine- to medium-grained limestone in ledges up to 10 feet thick, separated by yellowish marl. This is followed by a covered interval about 80 feet thick which is probably faulted. Above it is 90 feet of gray, bluish-gray, and brownish, fine-grained limestone in beds 1 to 10 feet thick with *Orbitolina texana*. The uppermost 18 feet is massive limestone with *O. texana* and is like the upper part of the Glen Rose southeast of Dog Canyon (Pl. VI, no. 8) and along the Marufo Vega trail (Pl. VI, no. 3).

Above the *O. texana*-bearing rocks is 30 feet of thin, bluish-gray limestone interbedded with clay. These rocks are considered to be Glen Rose because they are immediately below a sandstone believed equivalent to the Maxon; however, it is possible that this 30 feet of carbonates is also equivalent to the Maxon because King (1947, p. 114), Eifler (1943, pp. 1623–1625), and Graves (1954, pp. 19–20) reported that locally the Maxon contains layers of calcareous rocks and that the sandstone is replaced by or grades into marl and limestone toward the southwest. No fossils were found. Although both base and top of the Glen Rose occur here, the middle part has been faulted; as much as 355 feet of Glen Rose is exposed.

Dog Canyon.—About 3 miles southeast of Dog Canyon, 280 feet of upper Glen Rose is exposed which has not been faulted. Here (Pl. VI, no. 8) the conglomeratic sandstone and *Exogyra quitmanensis* are probably cut out by faults at the base of the section. In the lower half of this unit the limestone and marl beds are predominantly brown or reddish brown and above them the rocks are yellowish gray or gray brown. The top bed is a 10-foot ledge of brownish-gray limestone with *Orbitolina texana.*

Marufo Vega trail.—The Marufo Vega trail that gives access to the bottom of Boquillas Canyon traverses 245 feet of upper Glen Rose in a fault block about 3½ miles northeast of the head of the canyon (Pl. II; K, 28). The conglomeratic sandstone and *Exogyra quitmanensis* beds do not come to the surface and are probably cut out by a fault at the base of the section. The exposed rocks are limestone ledges alternating with marl. In the lower two-thirds of the section, the limestone is gray or yellowish brown and the interbedded marls are pink to pinkish brown. In the upper one-third, both the limestone and marl are gray or pinkish brown. The top bed is a fine-grained, gray limestone ledge about 10 feet thick. *Orbitolina texana* is present throughout the section but are most abundant in the lower beds.

Mexico: Sierra del Carmen.—In the Sierra del Carmen area in Mexico, immediately south of the Park, the base of the Glen Rose is a conglomerate, sand-

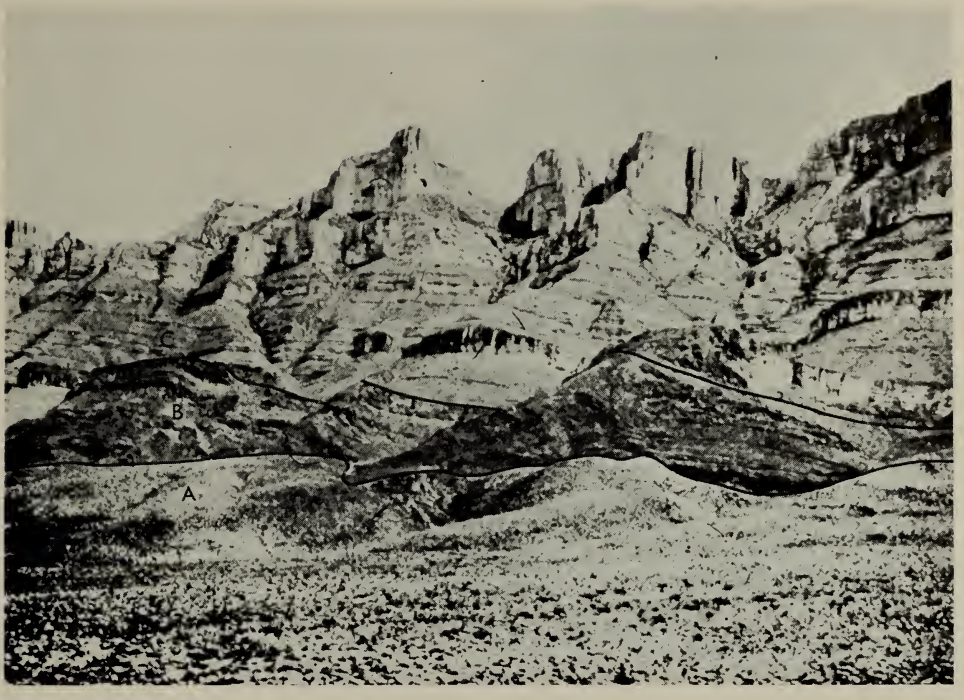


FIG. 16. Basal Cretaceous rocks in the Sierra del Carmen, Coahuila, Mexico.
A, Pre-Cretaceous metamorphic rocks. B, Basal sandstone and massive conglomerate. C, Glen Rose Limestone with *Exogyra quitmanensis* and *Orbitolina texana.*

stone, and red shale as much as 260 feet thick at one locality (fig. 16). This unit rests on metamorphic rocks, probably of Paleozoic age, and is overlain by limestone with *E. quitmanensis* and limestone containing numerous *O. texana.* The Glen Rose was not measured here but is much thicker than in the Park—perhaps as much as 1,000 feet thick.

Santa Elena Canyon.—The basal 100 feet of strata at the mouth of Santa Elena Canyon is gray and dark gray, nodular, and fine-grained limestone in 1- to 10-foot beds, alternating with marl and soft marly limestone (fig. 17). Except for their color these rocks are practically identical to the Glen Rose 3 miles southeast of Dog Canyon and along the Marufo Vega trail (Pl. VI, no. 1). The age of these beds is uncertain but the basal 100 feet is most likely Glen Rose, as was earlier suggested by Ross (1935, p. 563).

FOSSILS AND AGE

The following fossils were identified from the Glen Rose:

Douvilleiceras cf. *D. mammilatum* (Schlotheim, 1813)
Exogyra quitmanensis Cragin, 1893
Exogyra texana Roemer, 1852
Inoperna aff. *I. concentricecostellata* (Roemer, 1849)
Orbitolina texana (Roemer, 1852)
Porocystis globularis (Giebel, 1853)

Orbitolina texana and *Exogyra quitmanensis* are the most common fossils in the Glen Rose of Big Bend National Park. They are also the most useful for interpretation of the stratigraphy and structure. Ammonites, especially the genus *Douvilleiceras,* are common in the basal 200 feet at most Glen Rose exposures in west Texas, but only one identifiable specimen was found. *Porocystis globularis* is locally common. *Exogyra texana* has been recog-



Fig. 17. Mouth of Santa Elena Canyon.
A, Alternating limestone and marly beds (probably Glen Rose). B, Telephone Canyon Formation. C, Del Carmen Limestone. (Photograph by National Park Service.)

nized locally, and there are several unidentified species of pelecypods, gastropods, and echinoids. This faunal assemblage is of Glen Rose age but does not permit precise correlation with the Glen Rose in other parts of Texas.

FREDERICKSBURG GROUP

Maxon Sandstone

The Maxon Sandstone, the west Texas analogue of the Paluxy, was named by P. B. King (1930, p. 92) from exposures at Maxon Station on the Southern Pacific Railroad at the eastern rim of the Marathon Basin. At the type locality the Maxon forms conspicuous sandstone ledges above the Glen Rose about 100 feet above the valley floor. It forms ledges midway up the escarpments along the eastern side of the Marathon Basin and also occurs along San Francisco Creek (Dove Mountain quadrangle) and in the Del Norte Mountains. In Pecos County the equivalent basement sands of the Fredericksburg rest on Triassic? and Permian rocks.

According to King (1937, p. 114), the Maxon includes calcareous sandstone along San Francisco Creek, and the sandstone is absent south and southeast of the Jones ranch (Dove Mountain quadrangle), where its stratigraphic position is occupied by sandy shale and marly limestone. Near Black Peak (west-central Marathon Basin), strata beneath the Edwards are calcareous sandstone, in part cross-bedded, with conglomeratic and shaly limestone layers. Near Del Norte Gap, about 10 miles farther south, the same beds are marl and marly limestone with Walnut—Comanche Peak fossils. According to King, the Maxon Sandstone beds of the Marathon region are

replaced southward by marls of the Walnut and Comanche Peak Formations.

Eifler (1943, pp. 1622–1655) recognized the Maxon Sandstone in the Santiago Peak quadrangle. Although the unit is predominantly sandstone, in some places it contains conglomerate lenses and also includes sandy marl and marly limestone.

Graves (1954, pp. 19–21) mapped the Maxon Sandstone in the Hood Spring quadrangle. In that area it is mostly sandstone but contains sandy marls and lenses of fossiliferous limestone. It thins southward and becomes progressively more calcareous in that direction.

Local Features

The Maxon Sandstone was not recognized in the Park but it crops out about 1½ miles southeast of Persimmon Gap (Pl. IV), where it is a reddish-weathering, silty sandstone about 10 feet thick (Pl. VI, no. 9). The sandstone underlies marl and chalky limestone that were tentatively classified as Telephone Canyon beds and overlies 30 feet of marl and limestone without *Orbitolina texana*.

King, Eifler, and Graves have shown that north of the Park the Maxon changes facies within a short distance and is progressively more calcareous toward the south. Since the top 30 feet of marl and limestone in section 9 (Pl. VI) are not typical Glen Rose lithology, it is possible that at least part of this sequence is equivalent to the Maxon.

Telephone Canyon (New) Formation

The Telephone Canyon Formation is here named from thin nodular limestone and marl beds generally correlative with the Walnut Clay of central Texas that crop out in the Sierra del Carmen where Heath Creek excavated Telephone Canyon across the Sierra del Caballo Muerto (Pl. II; P, 26–28). At this type locality the formation is a soft lithologic unit that lies between the more resistant Glen Rose and the overlying hard, massive, cherty Del Carmen Limestone. The average thickness is about 75 feet. It crops out at several localities in the Sierra del Carmen, the southern end of the Santiago Mountains, and at the mouth of Santa Elena Canyon.

Local Features

Heath Creek.—The Telephone Canyon is exposed where Heath Creek (locally known as Telephone Canyon) crosses Sierra del Caballo Muerto (Pl. II; P, 26–28). The largest exposure includes about 75 feet of yellowish-gray and brownish-gray, marly, nodular limestone with yellowish marl partings (Pl. VI, no. 6). The marl decreases upward, and the top few beds are dense, flaggy limestone that is overlain with sharp contact by scarp-forming massive cherty limestone (Del Carmen). The base of the formation is covered with alluvium. Most beds are fossiliferous and the best preserved fossils collected from the formation are from the exposure on the south side of the canyon, along a bench that is normally above flood water.

Near the mouth of a lower canyon where Heath Creek crosses Hubert Ridge (Pl. II; P, 29) and extending southward along the eastern base of Hubert Ridge is a unit of marly limestone probably equivalent to the Telephone Canyon. Most of it is covered except where arroyos have cut through the debris mantle. The exposed rocks are like those at Telephone Canyon and lie in the proper stratigraphic position.

Marufo Vega trail.—About 2½ miles northeast of the head of Boquillas Canyon, the Marufo Vega trail crosses a small anticline (Pl. II; K, 28) with Telephone Canyon strata exposed in the crest. The strata are gray and yellowish-gray nodular limestone whose base is not exposed.

A mile farther northeast, the trail crosses the Telephone Canyon preserved along the face of a tilted fault block. The strata are

offset by a second fault and continue for about a mile northeast (Pl. II; K-M, 28). About 75 feet of gray and yellowish-gray marly limestone separates Glen Rose and Del Carmen (Pl. VI, no. 3).

Santiago Mountains.—In the southern end of the Santiago Mountains the strata have been severely faulted and folded. Although the Telephone Canyon unit was recognized in some areas, it could only locally be mapped or studied in detail. In the Love Ranch section (Pl. VI, no. 9), only the basal 20 feet of marly limestone occur. About 5½ miles southeast (Pl. II), 40 feet of soft marly limestone, mostly covered, separates Glen Rose and Del Carmen (Pl. VI, no. 8).

Santa Elena Canyon.—Telephone Canyon beds are exposed in a steep slope at the mouth of Santa Elena Canyon (Pl. II, G, 6) beginning about 100 feet above the average low-water level in the Rio Grande and extending upward to the bottom of the vertical (Del Carmen) limestone cliff (fig. 17). The summit of the canyon trail is near the base of the formation, and as it descends into the canyon, the trail is near the lower contact. The Telephone Canyon here is gray and yellowish-gray marl alternating with beds of gray and yellowish-gray, marly, nodular limestone and dark-gray nodular limestone. The formation is about 135 feet thick and separates the massive cherty Del Carmen Limestone in the lower sheer cliff above from strata that may be Glen Rose at the bottom of the canyon (Pl. VI, no. 1).

Fossils and Age

The following fossils were identified from the Telephone Canyon Formation:

Gryphaea mucronata Gabb, 1869
Tapes chihuahuensis Böse, 1910
Aporrhais tarrantensis Stanton, 1947
Exogyra texana Roemer, 1852
Metengonoceras cf. *M. ambiguum* Hyatt, 1903
Neithea irregularis Böse, 1910
Cardium sp.
Protocardium sp.
Tylostoma sp.
Enallaster sp.
Gryphaea sp.
Engonoceras sp.
Gyrodes sp.
Amauropsis sp.
Cyprimeria sp.
Trigonia sp.
Pholadomya sp.
Holectypus sp.
Phymosoma sp.
Turritella sp.
Nerinea sp.

Exogyra texana and *Gryphaea mucronata* are the most abundantly preserved fossils in the Telephone Canyon Formation and were found at all localities studied. *Metengonoceras* cf. *M. ambiguum*, *Tapes chihuahuensis*, and *Aporrhais tarrantensis* were collected at most places in the Sierra del Carmen and Santiago Mountains and *Neithea irregularis* was found only at Santa Elena Canyon. *Cardium* sp., *Protocardium* sp., *Tylostoma* sp., *Enallaster* sp., and *Turritella* sp. are common in most outcrops. The rocks containing this fossil assemblage are correlative, at least in part, with the Walnut and Comanche Peak rocks in central Texas.

Del Carmen (New) Limestone

The term Del Carmen Limestone is used in this report to designate a lithostratigraphic unit that in general corresponds to the Edwards Limestone in central Texas. The name Del Carmen is from the term Sierra del Carmen, a series of tilted fault-block mountains where the limestone is exposed. The Del Carmen Limestone normally forms a sheer escarpment in the lower part of the faulted fault blocks and is terminated both above and below by slopes that are underlain by soft limestone and shale. The formation ranges in thickness from about 350 feet in the Sierra del Carmen to 475 feet at the mouth of Santa Elena Canyon.

General Features

The Del Carmen Limestone is probably the most prominent Comanchean limestone in Big Bend National Park. It is mostly a rough-surfaced, fine- to medium-crystalline limestone, gray when fresh but weathering to shades of dark brown, yellowish brown, and pinkish brown. Brownish chert forms nodular or concretionary masses as much as 8 or 10 inches across and also forms lenticular bodies, some 10 feet or more long, parallel to obscure bedding. Except for the chert and some fossil debris, the beds are relatively pure limestone. The massive beds contain various rudistids and these locally constitute much of the rock. Marly layers are not normally conspicuous. The Del Carmen Limestone is exposed at many places in the Sierra del Carmen and the southern end of the Santiago Mountains. It forms part of the escarpment of Mesa de Anguila and the walls of Santa Elena Canyon and extends southward in the States of Coahuila and Chihuahua in northern Mexico.

Local Features

Santa Elena Canyon.—At the mouth of Santa Elena Canyon (Pl. II; G, 6), a nearly inaccessible body of Del Carmen forms the lower sheer face of the canyon wall (fig. 17). The limestone is fine-grained, dark gray and brownish in 8- to 10-foot beds. Some beds contain both nodular and lenticular brownish chert bodies, rudistids, and cross sections of other fossils. The authors climbed the mesa wall about 2 miles northwest of the mouth of the canyon where the upper 200 feet of Del Carmen is massive limestone. Here the beds average about 8 feet thick, are gray or bluish gray when fresh but weather to brown, rough surfaces, contain numerous irregular nodular chert bodies 6 to 8 inches across and also some chert layers as much as 2 inches thick and 2 to 3 feet long. Rudistids and cross sections of various pelecypods and a badly weathered ammonite were noted in the colluvium. Although the entire unit can also be traversed by a journey upstream in a boat, the rock walls are polished by abrasion to heights above the limit possible for clear observations (fig. 18).

The base of the Del Carmen is sharp and its massive, cherty limestone rests upon yellowish or gray marly limestone of the Telephone Canyon (fig. 19), usually making an overhanging ledge containing numerous caves. The top is also clearly defined as a bench of hard, cherty limestone that is overlain by a slope composed of the soft rocks of the Sue Peaks Formation. The Del Carmen Limestone was determined instrumentally to be 465 feet thick (Pl. VI, no. 1).

Marufo Vega trail.—About 3 miles northeast from the head of Boquillas Canyon, the Marufo Vega trail descends a steep narrow canyon cut into the Del Carmen Limestone (Pl. II; K, 28). This is one of the most accessible, nonfaulted exposures of the formation in the Park and is designated the type section. The beds are rough on the surface, light gray, bluish gray, and yellowish gray when fresh but change to brown and pinkish brown where weathered. They are aphanitic to crystalline limestone containing gray and bluish-gray chert that weathers brown. The chert forms in irregular nodules as much as 6 and 8 inches across and also forms in layers ¼-inch to 2 inches thick that extend in places for several feet parallel with the bedding. Most limestone layers are 8 to 10 feet thick; a few are only 1 to 2 feet thick. Most of them weather into vertical, square-cut faces and form steps along the bottom of the canyon. On both sides of the trail the Del Carmen forms a bold sheer escarpment, marked by small open caverns with overhanging ledges.

The top of the Del Carmen is at the top of a bench formed by the massive, cherty, rudistid-bearing limestone. Above is a slope formed by soft marl and marly limestone of the Sue Peaks Formation. The base of the Del Carmen is at the bottom of a massive, cherty, rudistid-bearing limestone which rests on soft marly limestone

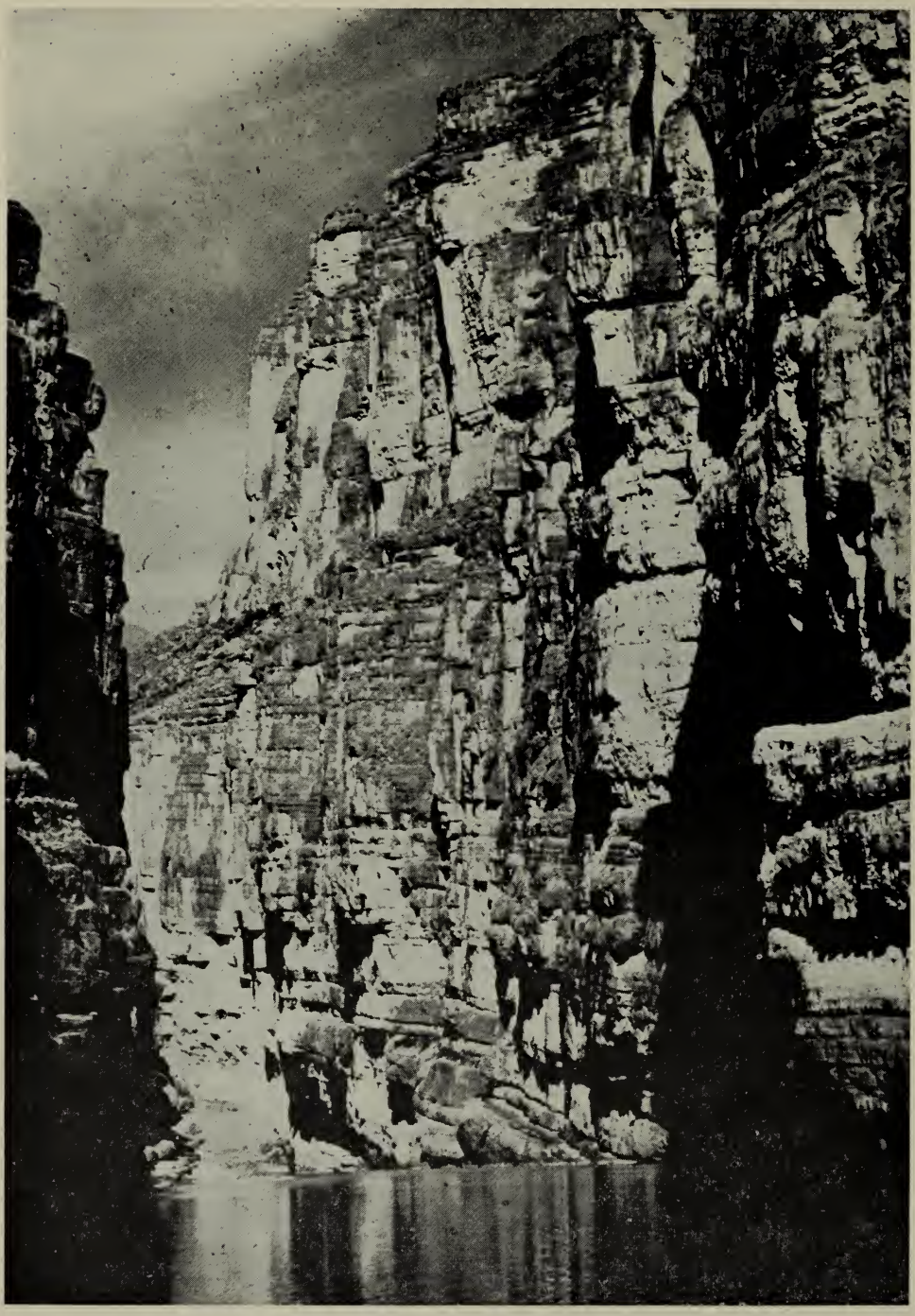


Fig. 18. Santa Elena Canyon. The sheer walls are Del Carmen Limestone.



FIG. 19. Basal Del Carmen contact, Santa Elena Canyon.
A, Telephone Canyon Formation. B, Del Carmen Limestone.

of Telephone Canyon. The softer Telephone Canyon strata below the Del Carmen have been undercut and form overhang shelters.

The formation is 338 feet thick, according to a hand-level traverse up the canyon (Pl. VI, no. 3). This thickness is comparable to others in the Texas Sierra del Carmen area but is about 125 feet less than in Santa Elena Canyon.

Sierra del Caballo Muerto.—The Del Carmen was traversed at several localities along the Sierra del Caballo Muerto (Pl. II; J–Q, 26–28). The formation is generally massive, finely crystalline or aphanitic limestone containing rudistids and chert and forms steep, square-faced escarpments. Most of the beds are between 6 and 10 feet thick but some are only 1 to 2 feet. The chert forms nodular masses as much as 6 inches in diameter as well as layers as much as 2 inches thick that commonly extend for several feet along the bedding. The chert is generally gray or bluish gray but weathers to various shades of brown. Rudistids occur throughout most of the formation but are more numerous in the upper and lower thirds of the unit. Because of faulting and erosion, the sequence is incomplete at several of the localities studied (Pl. VI, nos. 4, 5, 7).

A complete Del Carmen section is exposed on the south side of Telephone Canyon (Pl. II; P, 27), where it is 350 feet thick and is divisible into three lithologic units. The basal and upper units are massive, cherty, rudistid limestone and are separated by slope-making marl and marly limestone. The marl and marly limestone begin about 155 feet above the base of the Del Carmen and are 45 feet thick.

About 4 miles south of the locality above (Pl. II; N, 28–29) is a fine-grained, white limestone ledge about 20 feet thick, which is overlain by about 10 feet of gray and pinkish-gray flaggy limestone. The former is lithologically similar to part of the Buda, and the latter might be mistaken for Boquillas. These two units were traced south-

ward to near the Rio Grande. They are underlain and overlain by massive, cherty, rudistid-bearing limestone and are a local facies of the Del Carmen Limestone. The same lithologic units occur near the middle of the Del Carmen on the back slope of Hubert Ridge (Pl. II; O, 29) near the mouth of Boquillas Canyon.

Santiago Mountains.—Several faulted exposures of Del Carmen Limestone in the southern end of the Santiago Mountains (Pl. IV) were studied. The rock is massive, cherty, rudistid-bearing limestone that at most localities forms square-faced escarpments along the front of the mountain range. No prominent marl or soft limestone beds occur. One nonfaulted section (Pl. VI, no. 8), about 2½ to 3 miles southeast of the mouth of Dog Canyon, was studied in detail. It is less cherty than most of the formation but chert and rudistids do occur. Here again the massive limestone rests upon the marly nodular beds of the Telephone Canyon Formation, and the Del Carmen is overlain by soft strata of the Sue Peaks. A thickness computed from a hand-level survey is about 350 feet.

Fossils and Age

The following fossils were identified from the Del Carmen Limestone:

Exogyra texana Roemer, 1852
Protocardia texana (Conrad, 1857)
Pholadomya sanctisabae Roemer, 1849
Aporrhais tarrantensis Stanton, 1947
Eoradiolites cf. *E. davidsoni* Hill, 1893
Gryphaea sp.
Tapes sp.
Cardium sp.
Protocardium sp.
Turritella sp.
Tylostoma sp.
Radiolites sp.

Although fossils are present throughout the Del Carmen, identifiable specimens are rare. Fossils are seen in cross section along joints; they are difficult to remove from the hard rock and if removed are commonly damaged. Occasionally a weathered specimen is found on the surface, especially in the more marly beds.

Rudistids are the most common and are an important rock-forming constituent. One form is questionably *Eoradiolites davidsoni* and there are at least two other genera, one of which is *Radiolites?* sp. Correlation by rudistids is impossible until more is known regarding their range. Their presence marks a facies, and in the Park, rudistids occur in both the Del Carmen and Santa Elena Limestones, which are separated by the nonrudistid-bearing Sue Peaks Formation. Several species of pelecypods, gastropods, and echinoids, and two fragmental unidentifiable ammonites have been found. The pelecypod genus *Gryphaea* is common, and at two levels near the top of the formation where it is exposed along the Marufo Vega trail, there are thin beds composed largely of fragmental *Gryphaea*. The fauna indicates a Fredericksburg age and occurs in beds that are probably equivalent to at least part of the Edwards Limestone in central Texas.

Sue Peaks (New) Formation

The term Sue Peaks is used to designate the soft lithostratigraphic unit that forms a slope separating the sheer escarpments formed by the Del Carmen Limestone below from the Santa Elena Limestone above. The name is taken from Sue Peaks, highest elevation in the Sierra del Carmen. The rocks crop out in the eastern slope of Sue Peaks and other places in the Sierra del Carmen, Mariscal Mountain, Mesa de Anguila, and the Christmas Mountains. The formation is divisible into a lower shale member that is in part correlative with the Kiamichi and an upper limestone member correlative with the Duck Creek of northeast and central Texas.

General Features

The Sue Peaks slope, separating the Del Carmen Limestone below from the sheer Santa Elena Limestone escarpment above,



FIG. 20. Sue Peaks slope, along eastern side of Sierra del Caballo Muerto.
A, Top of Del Carmen Limestone. B, Lower shale member. C, Massive limestone ledge about 20 feet thick. D, Upper limestone member. E, Santa Elena Limestone.

is underlain by a soft rock unit normally about 250 feet thick (fig. 20). The lower 75 feet is mostly yellowish-gray and buff marly shale with a few beds of similarly colored thin, marly, nodular limestone. Above the 75-foot lower shale member is a ledge of massive gray limestone about 20 feet thick. Above the 20-foot ledge are thin, gray, nodular limestone beds and some yellowish-gray shale. The upper limestone member is terminated at the top by the massive, cherty, cliff-forming, rudistid-bearing limestone of the Santa Elena. Normally, there is much debris on the Sue Peaks slope and it is frequently difficult to find bedrock exposures.

LOCAL FEATURES

Sierra del Carmen.—In the Sierra del Carmen Mountains, the lower shale member ranges from 73½ to 79 feet thick. The best exposure, which is the type section, is on the eastern slope of the Sierra del Caballo Muerto about 1½ miles south of Heath Creek (Pl. II; O–P, 28). Here several short arroyos cut through the debris mantle and expose the bedrock along the sides of small channels (fig. 20). The following section was measured here.

Section on east slope of Sierra del Caballo Muerto, about 1½ miles south of Heath Creek (Pl. II; O–P, 28).

	Thickness (Feet)
Base of Santa Elena Limestone— Massive-bedded, cherty, rudistid-bearing limestone.	
Sue Peaks Formation—	
27. Covered	6.0
26. Chert bed containing silicified echinoids	0.5
25. Limestone, gray, fine grained, in beds 4 to 6 inches thick	4.0
24. Covered	19.0
23. Limestone, gray, fine grained, mostly covered	8.0
22. Coquina limestone, gray, consisting mostly of fragmental *Gryphaea*	3.0
21. Limestone, gray, interbedded with yellowish marl, mostly covered	8.0

20.	Covered	13.0
19.	Limestone, gray, with three chert beds 4 to 8 inches thick containing silicified echinoids	10.0
18.	Covered	13.0
17.	Limestone, gray, in ledge	3.0
16.	Limestone, gray, nodular, and yellowish marl, mostly covered	7.0
15.	Limestone, gray, thin bedded, fine grained	14.0
14.	Covered	7.0
13.	Limestone, yellowish gray, with shale partings	9.0
12.	Gray coquina limestone consisting mostly of fragmental *Gryphaea*	2.0
11.	Limestone, gray, and yellowish shale	10.0
10.	Covered	8.0
9.	Shale, yellow, marly, with a few thin limestone beds	13.0
8.	Limestone, gray, dove brown, fine to medium grained, in beds 1 to 5 feet thick, forms massive ledges, and contains Duck Creek-age ammonites	20.0
7.	Limestone, gray, nodular, in beds 8 to 12 inches thick separated by yellow shale beds 2 to 4 inches thick	6.0
6.	Shale, yellow, marly, with a few yellowish-gray limestone beds 2 to 4 inches thick	18.0
5.	Limestone, buff, fine grained	1.5
4.	Shale, yellow, marly, with a few thin nodular limestone beds	25.0
3.	Covered, probably shale	9.0
2.	Shale, yellow and buff, with a few platy limestone beds 2 inches thick	7.0
1.	Covered, shale at nearby localities	8.0
	Total thickness, Sue Peaks Formation	252.0

Del Carmen Limestone—
Massive-bedded, cherty, rudistid-bearing limestone.

Similar lithostratigraphic units, mostly covered, were studied on the west side of Sierra del Caballo Muerto about half a mile south of Heath Creek; in Boquillas Canyon (fig. 21) about 2½ miles below the head of the canyon (Pl. II; J, 29); along the Marufo Vega trail (Pl. II; J–K, 28); on the northeast side of Stairway Mountain adjacent to the Park on the east (off map); about 2 miles south of Dog



Fig. 21. Sue Peaks Formation in Boquillas Canyon.
A, Del Carmen Limestone. B, Sue Peaks Formation. C, Santa Elena Limestone.

Canyon (Pl. II; P, 4); and at the Love ranch (Pl. VI, no. 9) east of the Park (off map). The thickness of the lower shale and upper limestone members is uniform and the 20-foot ledge at the base of the upper limestone member is easily identified and can be followed by eye for several miles. The lithology of rocks varies from place to place but there is always a shale-marl member below the 20-foot ledge and a thin-bedded limestone unit above. The place with greatest lithologic change is about 2½ miles below the head of Boquillas Canyon, where the lower member is predominantly a dark shale containing several nodular coquina beds composed mainly of fragments of *Gryphaea* sp.

Santa Elena Canyon.—At the mouth of Santa Elena Canyon and along the northeast face of Mesa de Anguila, yellowish shale, yellowish-gray marl, and yellowish-gray and gray, thin-bedded, nodular limestone form a slope that separates the sheer canyon wall into upper and lower escarpments. Although the section at the mouth of the canyon is inaccessible (fig. 22), beds were studied in the canyon where the westward-dipping rocks crop out at water level (fig. 23) and along the mesa about 2 miles northwest of the mouth of the canyon.

The water-level exposure in the canyon (about 2 miles above the mouth) is mostly covered, but the underlying rocks appear to be mostly shale and soft limestone. The 20-foot ledge that is present in the Sierra del Carmen about 75 feet above the base of the formation was not seen, but the thickness of the debris-covered slope between the top of the massive Del Carmen Limestone below and the base of the Santa Elena Limestone is similar. At a place along the mesa escarpment, about 2 miles northwest of the mouth of the canyon, the slope between the sheer, massive limestone escarpments above and below is less covered. The interval is 265 feet thick, measured by triangulation at the mouth of Santa Elena Canyon (Pl. VI, nos. 1–2),



Fig. 22. Mouth of Santa Elena Canyon.
A, Del Carmen Limestone. B, Sue Peaks Formation. C, Santa Elena Limestone.



Fig. 23. Slope-forming sequence near water edge in Santa Elena Canyon. A, Del Carmen Limestone. B, Sue Peaks Formation. C, Santa Elena Limestone.

and is comparable in thickness to the Sue Peaks that forms the slope in the Sierra del Carmen. The rocks differ from the latter as the entire interval is predominantly marl without a limestone ledge containing the Duck Creek fauna part of the way up the slope.

Mariscal Canyon.—The Sue Peaks Formation at Mariscal Mountain has not been examined by the writers. The International Boundary and Water Commission (1951) showed Kiamichi on their strip map of the Rio Grande. The mapped outcrop is in the canyon, and the inaccessible slope shown in figure 24 is likely formed by the Sue Peaks Formation.

Fossils and Age

The following fossils were identified from the Sue Peaks Formation:

Oxytropidoceras bravoensis (Böse, 1910)
Oxytropidoceras geniculatum (Conrad, 1857)
Idiohamites fremonti (Marcou, 1851)
Exogyra texana Roemer, 1852
Cyprimeria texana (Roemer, 1852)
Cardium subcongesta Böse, 1910
Protocardium texana (Conrad, 1857)
Gryphaea cf. *G. navia* Hall, 1856
Tapes chihuahuensis Böse, 1910
Pholadomya sanctisabae Roemer, 1849
Aporrhais cf. *A. subfusiformis* (Shumard, 1853)
Lopha subovata (Shumard, 1854)
Enallaster texana (Roemer, 1852)
Enallaster mexicanus (Cotteau, 1890)
Cardium sp.
Craginites sp.
Pervinquieria sp.
Prohysteroceras sp.
Desmoceras sp.
Mortoniceras sp.
Homomya sp.
Neithea sp.
Gryphaea sp.
Gyrodes sp.
Trigonia sp.
Turritella sp.

No distinct fossil zones have been established in the Sue Peaks in Big Bend National Park. Fossils collected and identified by J. T. Twining from the lower shale member of the Sue Peaks at the exposure on the east side of the Sierra del Caballo



Fig. 24. Slope in the sheer wall of Mariscal Canyon.
A, Del Carmen Limestone. B, Sue Peaks Formation. C, Santa Elena Limestone.

Muerto (Pl. VI, no. 5) include *Oxytropidoceras bravoense*, *O. geniculatum*, and several fragments of a species representing a genus similar to *Pervinquieria*. This genus is not like the *Pervinquieria* of the Washita Group and may be new, or it may be the immediate ancestral form of the typical Washita *Pervinquieria*. *Exogyra texana*, *Cyprimeria* sp., *Trigonia* sp., *Protocardia* sp., *Homomya* sp., *Neithea* sp., *Gryphaea* sp., *Tapes* sp., *Turritella* sp., and *Enallaster* sp. also occur.

On the west side of Sierra del Caballo Muerto, about half a mile south of Heath Creek, 75 feet of Sue Peaks was examined (Pl. II; P, 27). It is also yellowish, nodular, marly limestone interbedded with yellowish marl (partly covered) (Pl. VI, no. 7). *Craginites* sp. and *Oxytropidoceras* sp. were collected and identified by J. T. Twining at this locality, as well as *Texanites texanus*, *Cyprimeria texana*, *Tapes chihuahuensis*, *Protocardia texana*, *Cardium subcongesta*, *Gryphaea* sp., *Enallaster texanus*, and *E. mexicanus*.

On the northeastern side of Stairway Mountain, adjacent to the Park on the east (off map), is 79 feet of yellowish-gray, nodular limestone interbedded with yellow marl which yielded the following fossils identified by J. T. Twining: *Oxytropidoceras* sp., *Craginites* sp., *Idiohamites fremonti*, *Prohysteroceras* sp., *Gryphaea* cf. *G. navia*, *G. hilli*, *Pholadomya sanctisabae*, *Trigonia* sp., "*Cardium*" sp., *Aporrhais(?) subfusiformis*, and *Enallaster mexicanus*. The sequence is underlain by brownish, massive-bedded, cherty, rudistid-bearing Del Carmen Limestone and overlain by a ledge of gray, nodular limestone with *Idiohamites fremonti*, *Pervinquieria* sp., and *Desmoceras sp.* The latter fauna is similar to that occurring in the basal Duck Creek Formation in north-central Texas.

In Boquillas Canyon about 2¼ miles below its head (Pl. II; J, 29), dark shale overlies massive-bedded, cherty, rudistid-bearing Del Carmen Limestone (fig. 21). At the top of the dark shale is a bed composed of fragments of *Gryphaea* sp. Below this bed are *Oxytropidoceras* sp. and *Gryphaea* sp. A few feet above the bed are *Craginites* sp. and *Pervinquieria* sp.

Santiago Mountains.—In the Love Ranch section (Pl. VI, no. 9), R. T. Hazzard identified *Oxytropidoceras* sp. and *Gryphaea* sp. in thin nodular limestone and marl 10 feet below a ledge of gray limestone that contains *Mortoniceras* sp. and *Gryphaea* sp.

Santa Elena Canyon.—In samples collected at the water level in Santa Elena Canyon, J. T. Twining identified the following: *Exogyra texana*, *Gryphaea* cf. *G. navia*, *Cyprimeria* cf. *C. texana*, *Protocardia texana*, "*Cardium*" sp., *Neithea* sp., *Turritella* sp., *Tylostoma* sp., and *Enallaster* sp.

At a locality about 2 miles northwest of the mouth of Santa Elena Canyon, J. T. Twining identified the following fossils from the lowest 150 feet of beds in the Sue Peaks: *Oxytropidoceras* sp., *Exogyra texana*, *Gryphaea* cf. *G. navia*, and poorly preserved molds and casts of *Neithea* sp., *Astarte* sp., *Cyprimeria* sp., *Homomya* sp., "*Cardium*" sp., *Turritella* sp., *Gyrodes* sp., *Tylostoma* sp., *Nerinea* sp., *Aporrhais(?)* sp., and *Enallaster* sp. *Exogyra texana* was found throughout the 150 feet of section, and *Oxytropidoceras* sp. was found at the top of the 150-foot interval but not above.

A 5-foot, gray, marly limestone immediately below the massive-bedded, cherty, rudistid-bearing Santa Elena Limestone of the upper escarpment yielded the following: *Idiohamites fremonti*, *Craginites* sp., *Gryphaea* sp., *Neithea* sp., two specimens similar to *Lopha subovata*, *Enallaster* sp., and two solitary cup corals.

The lower shale member of the Sue Peaks Formation commonly contains *Oxytropidoceras bravoense* and *O. geniculatum*, which are often associated with *Exogyra texana*, *Gryphaea navia*, *Cyprimeria texana*, *Cardium subcongesta*, *Protocardium texana*, *Tapes chihuahuensis*, *Enallaster texana*, and *Enallaster mexicanus*; occasionally there are *Craginites* sp. in the uppermost beds. Since the lower Sue Peaks contains several genera common to the fauna recorded from the Kiamichi, it is



Fig. 25. Santa Elena Limestone near Boquillas, Big Bend National Park.

concluded that the lower shale member is correlative with at least part of the Kiamichi in northeast and central Texas.

The 20-foot limestone ledge at the base of the upper limestone member contains *Craginites* sp., *Idiohamites fremonti*, *Pervinquieria* sp., *Mortoniceras* sp., *Desmoceras* sp., and *Prohysteroceras* sp. These are considered to be Washita-age ammonites, and the strata containing them in northeast and central Texas are assigned to the Duck Creek. In the Park, *Craginites*, usually considered as Washita, was found associated with *Oxytropidoceras* at some places. This association suggests either that there is no sharp break between the Fredericksburg and Washita rocks in the Park or that *Craginites* occurs in both. The faunal break, if there is one, occurs near the base of the 20-foot limestone ledge, and it is concluded that the upper limestone member correlates with at least part of the Duck Creek in central Texas.

Santa Elena (New) Limestone

The Santa Elena Limestone is named from the rocks that form the upper half of the sheer canyon wall at the mouth of Santa Elena Canyon (fig. 17). This is the type section and is correlative with the Georgetown Formation above the Duck Creek Limestone as exposed in most of central and northeast Texas. This massive limestone also caps most of Mesa deAnguila and the Mariscal and Christmas Mountains and is widely distributed in the Sierra del Carmen. The Santa Elena Limestone is about 740 feet thick at the mouth of Santa Elena Canyon, but erosion has removed variable thicknesses of the rocks in the Sierra del Carmen, and folds or faults have deformed the rocks in other areas.

GENERAL FEATURES

In the Park (Pl. II) the Santa Elena is a hard, light gray or white limestone when fresh but weathers to dark gray or shades of brown. It is usually finely crystalline in beds as much as 10 feet thick (fig. 25). Silicified fossils, especially rudistids, and rounded nodular chert masses are common in the massive beds. In some places the upper part of the formation contains soft marly intervals interbedded with the hard, massive limestone so that weathering and erosion produce a terraced topography (fig. 26). Locally, the massive-bedded, cherty, rudistid-bearing ledges are difficult to distinguish from the underlying Del Carmen. In general, the Santa Elena differs from the Del Carmen in that it has a lighter color, a smoother surface due to less chemical weathering, and most of the contained chert is nodular rather than in layers.

LOCAL FEATURES

Santa Elena Canyon.—The thickest Santa Elena section measured in the Park is at the mouth of Santa Elena Canyon (fig. 17), where about 740 feet of massive limestone was measured by triangula- it has a lighter color, a smoother surface tion. The strata are massive limestone, in 8- to 10-foot beds, containing nodular chert and silicified rudistids. The rock is gray when fresh but weathers brown. Chert nodules up to 6 inches across are common. Freshly broken chert nodules are usually yellowish gray but the outside commonly weathers to rusty brown. Farther northwest where the mesa escarpment is accessible, there are several marly intervals interbedded with hard layers that eroded to form steps along the mesa rim. Erosion of the soft rock layers has formed small caves and overhanging shelters. Most of the mesa rim is inaccessible, however, and a description of the sheer rock cliff was not obtained.

Sierra del Carmen.—The Santa Elena Limestone was examined at several places in the Sierra del Carmen, but there is no



FIG. 26. Marly sequences in upper Santa Elena Limestone at Mariscal Canyon.

complete section free from faulting or complex folding. The best exposed section is in the Sierra del Caballo Muerto 1½ miles south of Heath Creek where it is about 525 feet thick (Pl. VI, no. 5). Here the massive, cherty limestone beds rest upon the Sue Peaks. Locally, the soft Sue Peaks rocks have been eroded, leaving an overhanging ledge at the contact. The limestone beds average 10 feet thick and form a sheer escarpment. Erosion along joints provides access to a limited part of the rock wall. Bedding is indistinct and chert nodules are common along some beds, while others are heterogeneously scattered throughout the rock. The limestone is gray when fresh but weathered surfaces are brown. The gray surface of the fresh rocks where small rock slides have occurred is commonly streaked with pink or yellow. The cross sections of rudistids, pelecypods, and gastropods are frequently exposed along joints. Most of them seem to be more easily weathered than the enclosing rocks and give rise to small pits and cavities.

Mariscal Mountain.—The Santa Elena exposure at Mariscal Mountain outlines the structure of the faulted anticline. Most of the younger formations have been stripped from the crest of the fold, and small canyons give access to the upper few hundred feet of the section. Here there are soft marly limestone layers interbedded with the hard cherty layers and erosion has formed a terrace topography (fig. 26). Solution has been active along some joints which provide narrow passages to depths of 50 or more feet. One collapsed cavern about a quarter of a mile across and perhaps 300 feet deep was seen about 3 miles south of Mariscal mine (Pl. II; D, 20).

FOSSILS AND AGE

Rudistids are the most common fossils in the Santa Elena and in some places they are a common rock-forming constituent. They are most commonly seen in cross section along joints, but few of them weather out. Two specimens collected from the colluvium were tentatively identified by J. T.

Twining as *Eoradiolites* cf. *E. quadratus*. Numerous *Gryphaea* sp. fragments are found in some beds. Molds and casts of several unidentifiable pelecypods and gastropods were collected from the upper marly beds. The meager fossil collection indicates a Washita age, and the Park sequence is believed equivalent to at least some parts of the subdivided Washita section in north-central and northeast Texas, but it is most like the massive Georgetown Limestone in the lower Pecos Valley and to the Comanchean rocks in northern Mexico.

Del Rio Clay

The Del Rio Clay was named by Hill and Vaughan (1898, pp. 236–237) from Del Rio (Val Verde County), Texas. The Del Rio at the type locality is a persistent thin unit of greenish clay with thin limestone interbeds. It is recognizable from Austin in central Texas, westward past Del Rio, into west Texas. Adkins (1933, pp. 386–396) correlated the Del Rio with the north Texas unit Grayson Marl, suppressed the name Del Rio, and extended the name Grayson from Austin to west Texas. The Grayson was named by Cragin (1894, pp. 43–48) for fossiliferous marl and interbedded limestone in Grayson County, northeastern Texas. The writers accept Adkins' correlation of the Del Rio and Grayson and recognize that Grayson has priority. Nevertheless, they prefer the name Del Rio because the Park beds are much more like the type Del Rio than the type Grayson.

GENERAL FEATURES

The Del Rio is mostly clay with some interbedded, flaggy, siliceous limestone, friable sandstone, and thin beds of ferruginous clay. South and east of Del Rio the formation is about 200 feet thick but it thins rapidly northward to 50 feet. West of Del Rio it is about 75 feet thick near the Devils River, 30 feet thick at Comstock, 20 feet thick at the Pecos River, only a few feet thick at Pandale in northwestern Val Verde County, and is missing near Langtry. Farther west the Del Rio reappears, being 25 to 30 feet thick between Dryden and Sanderson, and is well developed west of the Del Norte Mountains. From there the Del Rio extends southward into Big Bend National Park.

In the Park the Del Rio crops out in the southern Santiago Mountains (Pl. II; P–Q, 3–5) and is about 120 feet thick in the vicinity of Dog Canyon. It extends southward along the western side of the Sierra del Carmen to the Rio Grande where it is less than 5 feet thick. The thin Del Rio interval occurs along the north bank of the Rio Grande at Sierra San Vicente (Pl. II; E–F, 23) and at Mariscal Mountain (Pl. II; A–E, 20–22) but northwestward it thickens to 100 feet on Mesa de Anguila (Pl. II; H–K, 1–4).

The differences in thickness of the Del Rio suggest irregularities of the floor on which the formation was deposited, post-Del Rio erosion, or both. A study of the fauna shows that *Exogyra arietina*, *Exogyra whitneyi*, *Haplostiche texana*, *Heteraster texana*, and *Enallaster calvini* occur in the lower and middle beds of the Del Rio, and that *Exogyra cartledgei* and *Stoliczkaia* sp. are found only in the upper beds. West of Langtry where the Del Rio is missing, the basal beds thin and disappear against the flanks of the Terrell Arch and the upper beds are absent. These conditions could have been formed by post-Del Rio uplift that permitted erosion to remove the formation from the crest of the arch prior to deposition of the Buda which rests on the Georgetown, or uplift that began early in Del Rio time that caused the sea to recede locally. At Dog Canyon and Mesa de Anguila, where the Del Rio is about 100 feet thick, fauna characteristic of both upper and lower beds are present. The Del Rio thins southward toward the Rio Grande and along the river; where the formation is less than 10 feet thick, only beds containing the upper Del Rio

fauna have been found. This suggests (1) a pre-Del Rio uplift that was not covered until late Del Rio time or (2) an uplift which resulted in the erosion of the lower and middle Del Rio prior to deposition of the upper beds.

LOCAL FEATURES

Dog Canyon.—The Del Rio is exposed in a prominent slope near the head of Dog Canyon (Pl. II; Q, 3), where it is about 120 feet thick (Pl. VI, no. 11). Much of the slope is covered but soft bluish and greenish-gray clay that weathers yellow and light brown is exposed in most of the arroyos (fig. 27). A few hard, platy, ferruginous shale layers are interbedded with soft clay in the lower half of the exposure. The upper surface of most of these is coated with *Haplostiche texana*, which is a common feature in the Del Rio. Fossils characteristic of both the upper and lower Del Rio are present.

Dagger Mountain.—On the west side of Dagger Mountain (Pl. II; O, 3), about 115 feet of Del Rio was measured (Pl. VI, no. 12), which is about the same as the section near Dog Canyon. Both the lower and upper Del Rio fauna occur. East of Dagger Mountain, a mile southeast of Dagger Tank (Pl. II; P, 4), is a similar but more fossiliferous deposit.

Alto Relex.—Four miles north of Alto Relex (Pl. II; Q, 24) about 20 feet of Del Rio is exposed in a cut bank. The base is covered but the entire Del Rio unit is less than 30 feet thick. Several specimens of *Exogyra cartledgei* were found in the top foot of the exposure. About 12 feet below the top is a layer, 6 to 8 inches thick, filled with *Exogyra arietina* associated with *Haplostiche texana*, *Enallaster calvini*, and *Turritella* sp.

Boquillas.—Along the road to Boquillas, near benchmark V. T. R-2, is a small mound of Del Rio (Pl. II; J, 26), not more



Fig. 27. Del Rio and Buda exposure near Dog Canyon.
A, Del Rio Clay. B, Basal limestone member of Buda. C, Middle marly limestone member of Buda. D, Upper limestone member of Buda. E, Boquillas Formation.

than 5 feet thick, that rests on Santa Elena and is capped by Buda (fig. 28). Upper Del Rio fossils collected at this locality include numerous specimens of *Stoliczkaia* sp., a small ammonite, elongate forms of *Exogyra cartledgei*, and *Gryphaea* cf. *G. mucronata*. Fossils characteristic of the lower Del Rio are absent. On the Mexican side of the Rio Grande, about a quarter of a mile below Hot Springs (Pl. II; H, 26), the Del Rio is not more than a foot thick (fig. 29). No fossils occur but the proximity to and the almost continuous outcrop connecting these beds with the locality described above indicate they are also uppermost Del Rio.

Sierra San Vicente—Mariscal Mountain.—A thin band of Del Rio flanks most of Sierra San Vicente and Mariscal Mountain. It is less than 5 feet thick and not well exposed at Sierra San Vicente (Pl. II; E–F, 23) nor at the north end of Marsical Mountain (Pl. II; A–E, 20–22). Where the rocks have gentle dip, the Del Rio forms a narrow terrace between the Santa Elena and Buda Limestones, similar to the exposure near Hot Springs (fig. 29), but where the dip is steep it forms a narrow trench. Ross (1935, p. 563) reported clayey material, possibly Del Rio, in the shaft at Mariscal mine, and Schuette (1930, p. 39) recognized Del Rio on the surface. Farther south along the west side of Mariscal Mountain, where the Del Rio is about 10 feet thick, upper Del Rio fossils, damaged during folding, were collected.

Mesa de Anguila.—About 100 feet of Del Rio occurs on top of Mesa de Anguila (Pl. II; H–K, 1–4); it is mostly light blue and greenish clay that weathers yellow. Scattered bands of thin siliceous limestone and brown ferruginous clay with *Haplostiche texana* are found in the lower half of the outcrop and gray calcareous nodules occur in the top foot. Fossils characteristic of both the lower and upper Del Rio are present. Adkins (1933, pp. 392–393) re-



Fig. 28. Del Rio Clay near Boquillas.
A, Top of the Santa Elena Limestone. B, Del Rio Clay. C, Buda Limestone.



Fig. 29. Del Rio Clay, near Hot Springs on the Mexico side of the Rio Grande.
A, Santa Elena Limestone. B, Del Rio Clay, about 1 foot thick. C, Buda Limestone. D. Boquillas Formation.

ported upper Del Rio fossils from the Terlingua district, where the formation is 120 to 180 feet thick, and in the Solitario, where it is about 125 feet thick.

FOSSILS AND AGE

The following fossils have been identified from the Del Rio in Big Bend National Park:

Exogyra arietina Roemer, 1852
Exogyra cartledgei Böse, 1919
Exogyra whitneyi Böse, 1919
Gryphaea graysonana Stanton, 1947
Gryphaea cf. *G. mucronata* Gabb, 1869
Haplostiche texana (Conrad, 1857)
Enallaster calvini Clark, 1915
Heteraster texana (Roemer, 1852)
Stoliczkaia sp.
Turritella sp.

Some knowledge of the range for certain Del Rio fossils is desirable in order to determine what part or parts of the formation are exposed. In the lower Del Rio, where *Exogyra arietina* is commonly abundant, *Exogyra graysonana* is rare, but *E. graysonana* is normally abundant higher up where *E. arietina* is sparse; *Exogyra arietina* ranges upward into the Buda. *Exogyra arietina* is usually associated with *Haplostiche texana*, *Enallaster calvini*, and *Heteraster texanus*. The echinoids may range through the formation but are most abundant in the middle part. *Haplostiche texana* has not been found in the upper Del Rio. The *Exogyra arietina* and associated species are absent in the uppermost Del Rio which contains *Exogyra cartledgei* and *Stoliczkaia* sp.; the latter are not found in the lower part of the formation. The rocks in the Park correlate with part of the Del Rio at the type locality in Val Verde County.

Buda Limestone

General Features

Buda Limestone was named from the town of Buda (Hays County), Texas, by

Vaughan (1900b, p. 18). In central Texas most of the Buda is a crystalline limestone containing fossil shells, shell fragments, and glauconite flakes that weather red on the surface, giving rise to the old descriptive title "burnt limestone." It crops out intermittently from central to west Texas; in most of west Texas the Buda includes both compact, fine-grained, hard, and soft, nodular, marly limestone beds but a rudistid facies occurs at Del Rio and near Sierra Blanca. The Buda is unconformably overlain by Gulfian formations. In most areas it overlies the Del Rio conformably but locally in southwest Texas, on the Terrell Arch, the Buda rests on Georgetown.

In Big Bend National Park, the Buda crops out along the west side of the Santiago-Sierra del Carmen ranges, from the vicinity of Dog Canyon on the north (Pl. II; Q, 3) southward to the Rio Grande. It is present in the northwest flank of Sierra San Vicente (Pl. II; E–F, 23), borders most of Mariscal Mountain (Pl. II; A–E, 20–22), is present locally on Mesa de Anguila (Pl. II; H–K, 1–4), and flanks the southern and southeastern sides of the Christmas Mountains (Pl. II; P–Q, 11–12). In the Park the Buda is divided into (1) a basal limestone member, (2) a middle marly nodular limestone-marl member, and (3) an upper limestone member. The three-fold division can be traced eastward to Del Rio and southward into adjacent parts of Mexico. The thickness is mostly less than 100 feet. Pre-Gulfian erosion caused at least some of the thickness variation; in places small karstlike depressions on the surface seem to be the result of subaerial erosion that took place prior to deposition of the Gulfian formations.

LOCAL FEATURES

Dog Canyon.—Southwest of Dog Canyon (Pl. II; Q, 3) is 115 feet of Buda Limestone (Pl. VI, no. 11). The basal limestone member is about 25 feet thick (fig. 27) and consists of gray-white, fine-grained, hard limestone with conchoidal fracture; weathered surfaces have yellow spots. The beds are 2 to 6 feet thick, are resistant to erosion, and form a ledge above the soft Del Rio Clay. The middle marly nodular limestone-marl member is about 30 feet thick and consists of gray, nodular, marly limestone interbedded with gray marl that weathers to a lumpy surface and forms a conspicuous slope between the upper and lower limestone members. The upper limestone member is like the basal member and is about 60 feet thick. It is gray-white, fine-grained, hard limestone with conchoidal fracture. There are yellow spots on weathered surfaces and the beds break along joints forming square-faced ledges.

Dagger Mountain.—A Buda section 70 feet thick (Pl. VI, no. 12) was measured on the west side of Dagger Mountain (Pl. II; O, 3). The lithology is the same as at Dog Canyon but the upper limestone member at Dagger Mountain is only 25 feet thick. Although the two sections are separated by an airline distance of only 3½ miles the difference in thickness is interpreted as being due to erosion of the uppermost Buda prior to deposition of the basal Gulfian formation.

Sierra del Carmen.—The Buda Limestone is exposed at most places along the west side of the Sierra del Carmen from Dagger Mountain, at the north, southward to the Rio Grande (fig. 30). Generally it forms conspicuous hogbacks that can be traced by eye for long distances; in places it is repeated by faults. The three members are present but normally there is less limestone and more marl in the middle member toward the south. The thickness of the two lower members is uniform, but there is considerable variation in thickness of the upper limestone member due to post-Buda erosion. In the Boquillas-Hot Springs area (Pl. II; H–K, 26–27) only the lower Buda is preserved from recent erosion on many of the isolated mounds (Pl. VI, no. 13).

Mariscal Mountain.—Buda Limestone forms a prominent hogback around most of Mariscal Mountain (Pl. II; A–E, 20–22). The lower and, in places, part of the



FIG. 30. Buda Limestone along the west side of the Sierra del Carmen.

A, Top of the middle marly limestone member. B, Upper limestone member, which at this locality does not exceed 20 feet in thickness. C, Boquillas Formation.

middle, member caps many of the mounds on the eastern slope. When the upper member is present it is only about 10 feet thick, and probably more post-Comanchean erosion occurred here than at Dog Canyon farther north. Perhaps the same structure that caused thinning of the Del Rio was uplifted again near the end of the Comanchean.

Mesa de Anguila.—The Buda caps several isolated mounds on Mesa de Anguila and in places where the Boquillas is present, forms low cuestas. The three members occur and the rocks are like those described at Dog Canyon, but the total thickness is only about 70 feet. The difference is chiefly in the upper limestone member, which averages about 25 feet thick. The rocks dip at a low angle and a low undulating erosion surface can be seen at the Buda-Boquillas contact in a few places.

FOSSILS AND AGE

The following fossils were collected from the Buda Limestone:

Exogyra clarki Shattuck, 1903
Gryphaea graysonana Stanton, 1947
Gryphaea sp.
Lima wacoensis Roemer, 1849
Pecten roemeri Hall, 1889
Budaiceras spp.
Enallaster calvini Clark, 1915
Heteraster sp.
Trigonia sp.
Tylostoma sp.
Turritella sp.

Fossils are rarely found in the fine-grained limestone and, if found, are difficult to remove without damage. Most of the collection came from the middle marly unit; the fossils are of late Comanchean age and the rocks containing them correlate with the Buda in central Texas.

Gulfian Series

GENERAL FEATURES

Gulfian series was applied by R. T. Hill (1887, p. 298) to strata between the base of the Woodbine and the base of the Midway. The series includes a basal sandstone, shallow marine clay, marl, chalk, argillaceous limestone, continental deposits of limestone, coal and clay, eolian deposits, and pyroclastics. Gulfian formations crop out over a wide area of Texas including the Big Bend where Udden (1907a) laid the framework for the stratigraphy and structure by his early work in the Chisos Mountains-Terlingua area. More recent field investigations have led to the discovery of additional fossil localities, have modified his nomenclature, and have redefined some of his formations.

The Terlingua is here redefined as a group which includes the Boquillas and Pen Formations. The Boquillas Formation, oldest Gulfian lithostratigraphic unit, now includes Udden's (1907a, pp. 29–33) Boquillas Flags and the lower member of his Terlingua Beds. The middle and upper members of Udden's (1907a, pp. 33–41) Terlingua Beds are renamed the Pen Formation. The Rattlesnake Beds of Udden (1907a, pp. 41–57) were renamed Aguja Formation by Adkins (1933, p. 505) because "Rattlesnake" was already in use for an Oregon Pliocene formation. Vertebrate paleontology studies by J. A. Wilson et al. (1952, p. 7) have shown that a considerable portion of Udden's (1907a, pp. 54–60) Tornillo, which he classed as Cretaceous, is of Tertiary age, and the Chisos Beds that Udden (1907a, pp. 60–66) tentatively classed as Cretaceous are upper Eocene and younger (table 3, p. 57).

Boquillas Formation

GENERAL FEATURES

The Boquillas Flags were named by Udden (1907a, pp. 29–33) from the old Boquillas post office, which in 1907 was on Tornillo Creek (Pl. II; K, 24) about 7½ miles northwest of the present-day Boquillas. In this report the Boquillas has been expanded to include also the lower member of Udden's (1907a, pp. 33–41) Terlingua Beds. The term as redefined includes a lithostratigraphic unit of argillaceous limestone and chalk flags that are separated by thin layers of calcareous clay. The formation is divisible into two members, the Ernst below and the San Vicente above. These are separated by an erosion surface but the beds below the diastem are so nearly like those above that it is difficult to distinguish between them unless they are fossiliferous.

ERNST (new) MEMBER

The term Ernst, named from Ernst Tinaja about 2 miles east-northeast of the old Boquillas post office, is used to designate the lower member of the redefined Boquillas Formation. The Ernst Member is of Eagle Ford age and is approximately equivalent to Udden's original Boquillas Flags.

In Big Bend National Park, the Ernst is about 450 feet thick and consists of silty limestone flags, siltstone, and calcareous clay. The flagstones are usually 2 to 5 inches thick, but some beds are as much as 10 to 18 inches thick. The clay partings are not prominent on fresh surfaces, but in vertical weathered surfaces they disintegrate like mortar in an old brick wall, leaving the harder flagstones prominently exposed (fig. 31).

The common weathered color of both flagstone and clay is light yellowish gray or buff, but the flagstone and clay are bluish gray on fresh surfaces. The more siliceous beds weather to various shades of brown. The flagstones are hard, tough, break with a metallic ring, and many have a petroliferous odor. They are jointed and break into long blocks with straight faces,



FIG. 31. Basal Ernst beds in north bank of the Rio Grande, north of Sierra San Vicente.



FIG. 32. Buda-Ernst contact in north bank of the Rio Grande about one-quarter mile below Hot Springs (Pl. II; H, 26). Man seated on top of Buda with right hand on Boquillas.

TABLE 3.—Usage of formation names by Udden, by Adkins, and in this report.

UDDEN (1907a, pp. 29–70)	ADKINS (1933, pp. 431–516)	THIS REPORT
Burro Gravels and Tuffs	Cenozoic lava	TERTIARY, Big Bend Park Group: South Rim Formation
?	?	
Crown Conglomerate	Crown Conglomerate	Chisos Formation
*Chisos Beds	Chisos Beds	
?	?	Canoe Formation
CRETACEOUS: **Tornillo Clays	CRETACEOUS: **Tornillo Clay	TERTIARY, Tornillo Group: Hannold Hill Formation
		Black Peaks Formation
		Javelina Formation
***Rattlesnake Beds	***Aguja Formation	CRETACEOUS: Aguja Formation
Terlingua Beds	Taylor Clay	Terlingua Group: Pen Formation
	Austin Chalk	Boquillas Formation: San Vicente Member
Boquillas Flags	Boquillas Flags	Ernst Member

*Udden (1907a, p. 66) tentatively assigned a Cretaceous age.

**Both Udden (1907a, pp. 54–60) and Adkins (1933, p. 508) assigned a Cretaceous age to the Tornillo based on vertebrate fossils from the lower part. Tertiary-age formations (Canoe, Hannold Hill, and Black Peaks) were not recognized.

***Rattlesnake Beds named by Udden (1907a, p. 41). Name "Aguja" introduced by Adkins (1933, p. 505) to replace preëmpted term Rattlesnake.

commonly with greater width than thickness.

The Ernst member overlies the Buda Limestone; the basal beds are sandy or silty flagstone (fig. 32). Locally the basal few feet are intricately folded, probably by slumps or slides on the eroded Buda surface (fig. 33). The basal 100 feet of Ernst is commonly streaked with reddish brown, purple, or pink. This color is prominent in both the flagstone and clay partings and is especially conspicuous along the Rio Grande, and to a lesser extent in the outcrops along the west side of the Sierra del Carmen. This characteristic color also occurs in the basal Boquillas beds along Fresno Creek in eastern Presidio County and in Terrell and Val Verde counties.

About 330 feet above the base of the Ernst is a 3-foot ledge of brown siliceous flagstone with shale partings, containing

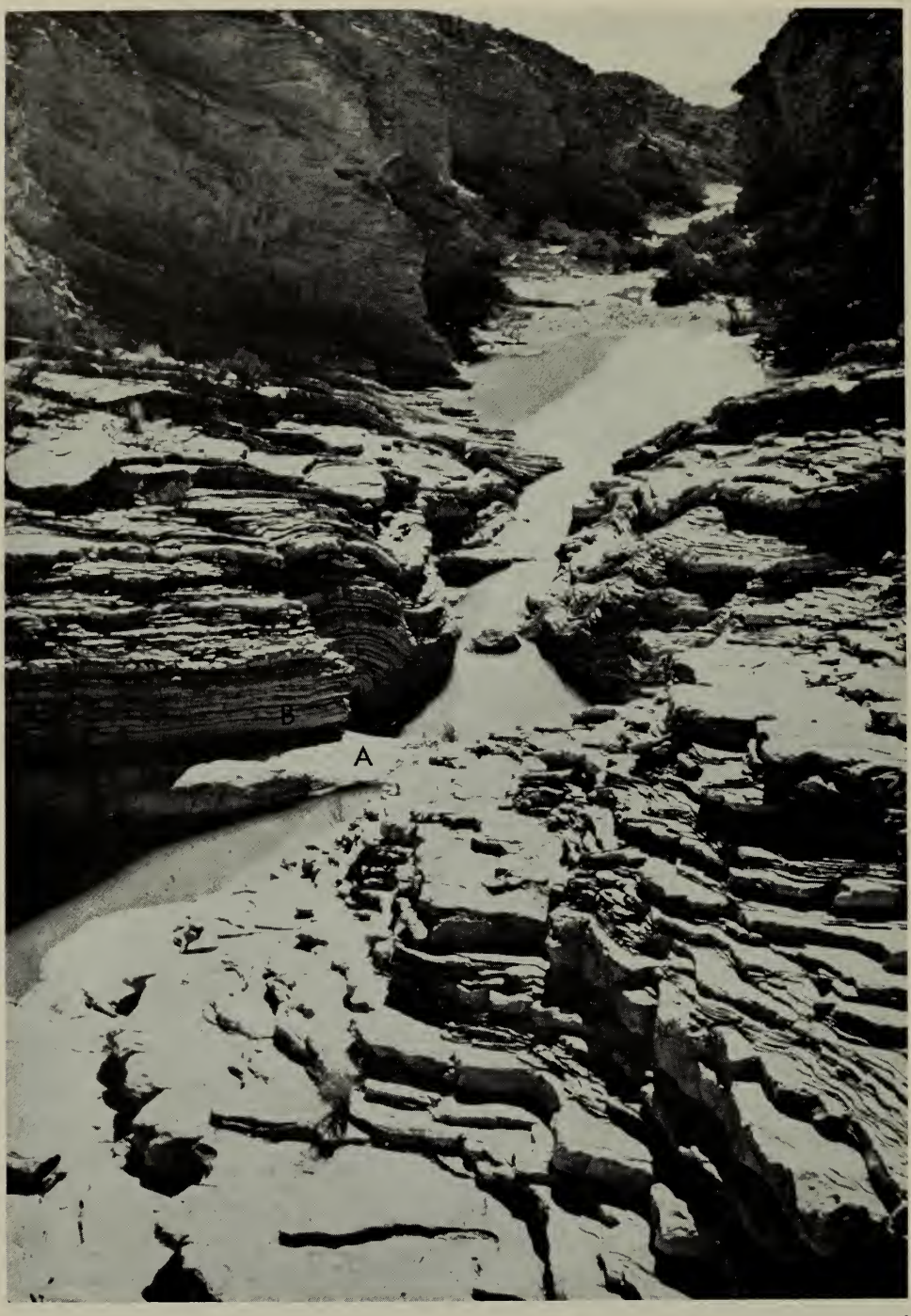


FIG. 33. Buda-Ernst contact near Ernst Tinaja in Cuesta Carlota (Pl. II; L, 25). Note folded beds at base. A, Buda Limestone. B, Ernst Member.

numerous *Allocrioceras hazzardi* (fig. 34), which forms a low cuesta that can be traced for long distances. The *Allocrioceras* is associated with *Scaphites* sp., *Scipinoceras* cf. *S. gracilis*, and an unidentified discoidal ammonite. The *Allocrioceras* was observed by Udden (1907a, p. 43) and by Adkins (1933, p. 451) and is shown on the geologic map (Pl. II) by the symbol "cccc."

About 100 feet above the top of the *Allocrioceras* beds is the beginning of a sequence in which some flagstones are as much as 18 inches thick; they contain the large flat ammonite *Coilopoceras* sp. These beds are well exposed about a mile northeast of the old village of San Vicente (Pl. II; H, 25), near the top of the gorge occupied by the road to Hot Springs (Pl. II; H, 25), and along the western flank of the Sierra del Carmen (figs. 35 and 36). The top of the *Coilopoceras* beds is the top of the Ernst Member at most localities in the Park. The base of the overlying San Vicente is conglomeratic, and the unconformable contact is exposed about 1 mile northeast of the old San Vicente village where the old Hot Springs road follows near the contact for about 2 miles and along the west side of the Sierra del Carmen. Locally, as east of the Park road crossing at Bone Spring Draw (Pl. II; Q, 2), the *Coilopoceras* beds have been eroded and the basal San Vicente is within 25 feet of the *Allocrioceras* beds.

LOCAL FEATURES

San Vicente—Hot Springs area.—In this area the Ernst sequence is not faulted and affords an excellent section. The base of the Ernst Member, lying on Buda Limestone, occurs on the north bank of the Rio Grande about a quarter of a mile below Hot Springs (Pl. II; H, 25). Its lower beds (fig. 32), which form the slope along the river valley, are purplish, pink, and gray silty flagstone interbedded with clay; the lowermost beds are sandy. The interval from the base of the Ernst to the top of the *Allocrioceras* beds, as measured by plane-table (Pl. VII, no. 22), is 335 feet thick. The following is a stratigraphic section measured here.

Section of Ernst Member (measured by plane-table), base of formation to top of Allocrioceras *beds, about a quarter of a mile below Hot Springs* (Pl. VII, no. 22).

		Thickness (Feet)
13.	*Allocrioceras* beds. Siliceous limestone, brown, case-hardened, in 2- to 5-inch beds, interbedded with light-brown and yellowish-gray arenaceous shale, 2-inch beds. Contains *Allocrioceras hazzardi*, at least one species of *Scaphites*, *Scipinoceras* cf. *S. gracilis*, and small unidentified desmoceratid ammonites	3
12.	Limestone, gray to buff, thin, compact, fine grained, flaggy, argillaceous, in 2- to 2¼-inch beds, interbedded with platy shale	45
11.	Limestone, buff, argillaceous, flaggy, with thin shale partings; weathers into rectangular plates which ring when struck with hammer. Forms a conspicuous ridge, at the top of which is a prominent 1-foot bed of light gray, slightly sandy limestone	68
10.	Limestone, buff and yellowish gray, argillaceous, sandy 2- to 4-inch beds with interbedded 1- to 6-inch shale bands. Six units of similar character 6 to 10 feet thick form low ridges, which are separated by shallow depressions formed by yellowish shales, partly covered	55
9.	Limestone, brownish and buff, hard, compact, argillaceous, flaggy, in 4- to 8-inch beds, separated by shale partings less than an inch thick. The limestones alternate with buff shales containing occasional 1½- to 3-inch flagstones	35
8.	Limestone, buff, hard, compact, argillaceous, flaggy, in 4- to 9-inch beds, separated by shale partings, forming units as much as 8 feet thick, separated by greater thicknesses of platy and flaggy purple-weathering shale containing carbonaceous material. Top bed is iron-stained sandy limestone a foot thick	41
7.	Shale, platy, fissile, calcareous, weathering mottled and purple; some thicker plates weather into biscuit-shaped nodules	32
6.	Limestone, grayish brown, arenaceous, flaggy, in 4- to 8-inch beds, separated by buff shale partings, containing a few small ammonites	6

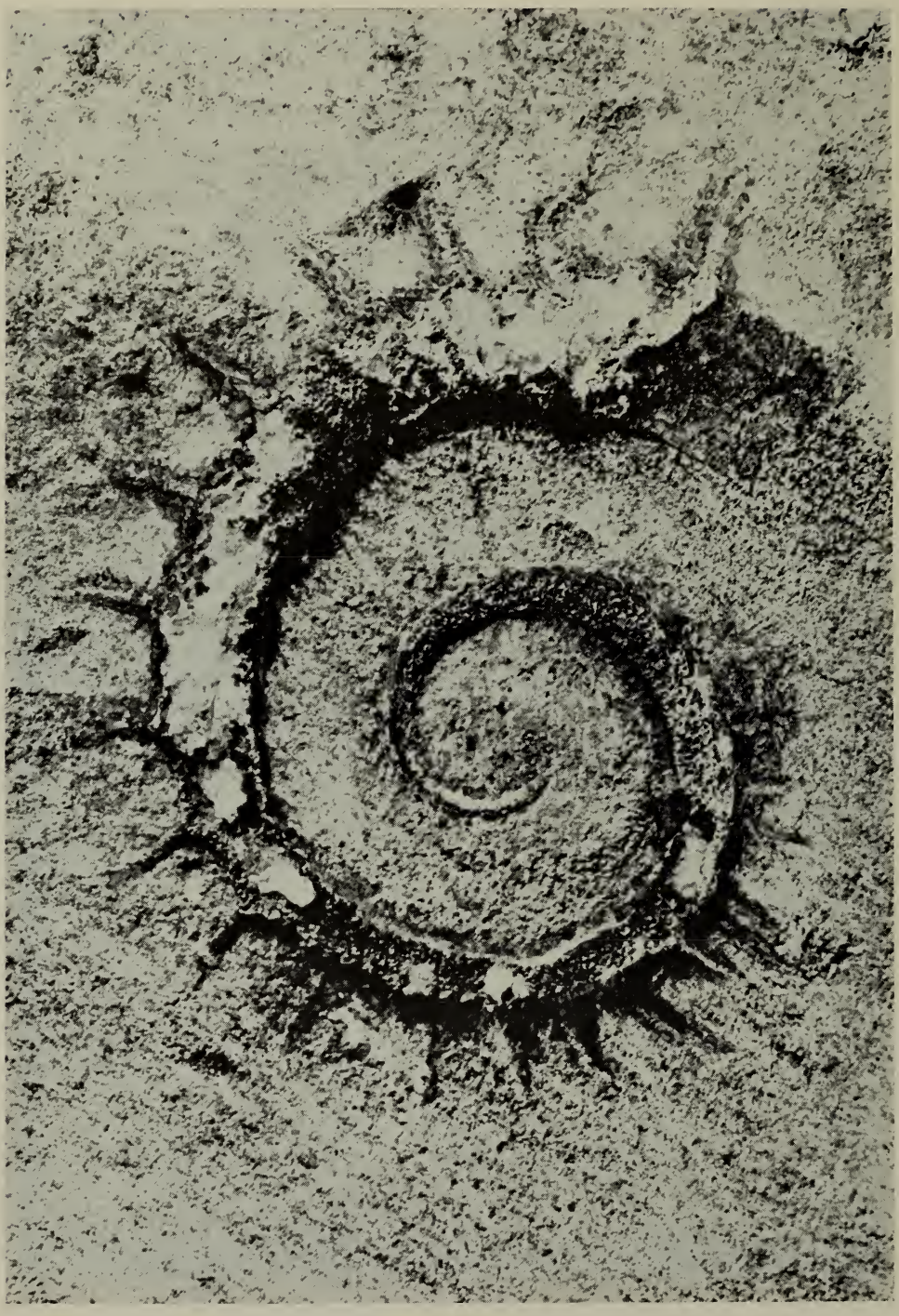


FIG. 34. *Allocrioceras hazzardi* Young. x3.



FIG. 35. Debris veneer on top of *Coilopoceras* beds about 1 mile northeast of San Vicente (Pl. II; H, 25).

A, Top of *Coilopoceras* beds. B, Base of San Vicente Member. The erosion surface between the Ernst and San Vicente Members is at the base of the escarpment.



FIG. 36. Entrance road to Hot Springs; near base of San Vicente Member.

A, Top of *Coilopoceras* beds. B, Base of San Vicente Member. The erosion surface at base of San Vicente Member is at road level.

	Thickness (Feet)
5. Limestone, grayish brown, flaggy, in 2- to 4-inch beds separated by softer flaggy shale, mottled and streaked by weathering to pink, reddish brown, and purple	16
4. Flagstone, brownish gray, argillaceous, in 3- to 5-inch beds with thin buff shale partings; contains a small desmoceratid ammonite	4
3. Limestone, pink and reddish brown, argillaceous, flaggy, in 2- to 4-inch beds interbedded with mottled pink and reddish-brown flaggy shale	13
2. Limestone, gray and buff, argillaceous, flaggy, containing small ammonites	5
1. Limestone, gray to yellowish brown, finely crystalline, aphanitic, flaggy, containing scattered sand grains, interbedded with gray and pinkish shale. Miniature folds are prominent in basal 3 feet; disconformity at base	12
Total	335

Buda Limestone—gray white, hard, aphanitic, crystalline.

The Ernst Member crops out along the western slope of the Sierra del Carmen northward from the Rio Grande nearly to Persimmon Gap. About 1½ miles north of the Rio Grande, it is 469 feet thick (Pl. II; J, 25–26), but much of it is covered. So far as exposed, the member is like that at the previous locality, and both the *Allocrioceras* and *Coilopoceras* beds occur (fig. 37, no. 1). The interval between the top of the *Allocrioceras* beds and the base of the formation is 341 feet thick, or 6 feet more than in the preceding section. (See following section.)

Section of Ernst Member (measured by plane-table) about 1½ miles north of the Rio Grande (Pl. VII, no. 21).

	Thickness (Feet)
San Vicente Member.	
Diastem.	
Ernst Member—	
6. *Coilopoceras* beds, upper 5 feet, limestone, gray to slightly brownish gray, almost lithographic, in 5- to 12-inch beds, interbedded with 4-inch beds of yellowish-gray, soft, platy, calcareous clay and siltstone	30
5. Limestone, gray and buff, flaggy, in 1- to 4-inch beds, separated by 1- to 2-foot bands of gray, silty clay and marl, much covered	98
4. *Allocrioceras* beds. Limestone, brown, case-hardened, siliceous, in 2- to 5-inch beds separated by 2-inch seams of yellowish-gray and light-brown shale. *Allocrioceras hazzardi* and associated fossils are common on the upper surfaces of the siliceous limestone	3
3. Limestone, gray to buff, flaggy, in 1- to 4-inch beds separated by shale partings, interbedded to 50-foot units of gray, soft shale, mostly covered	236
2. Limestone, gray, flaggy, argillaceous, with thin shale partings containing small ammonites and fragments of *Inoceramus* sp.	10
1. Limestone, yellowish gray, flaggy, argillaceous, 2- to 4-inch beds forming thin ledges, interbedded with gray, yellowish-gray, and mottled pink and purple shale. The basal few feet are chiefly brownish, sandy limestone flags. Small desmoceratid ammonites occur 2 feet above the base. Disconformity at base	92
Total	469

Buda Limestone.

The upper part of the Ernst Member is well exposed (fig. 35) a mile northeast of San Vicente (Pl. II; H, 25). Here a dozen or more *Coilopoceras* specimens may be found in place on the surface of the flagstone beds along a dip slope. The thickness of the interval from the top of the *Allocrioceras* beds to the base of the San Vicente is 130 feet (Pl. VII, no. 23). The section here is as follows.

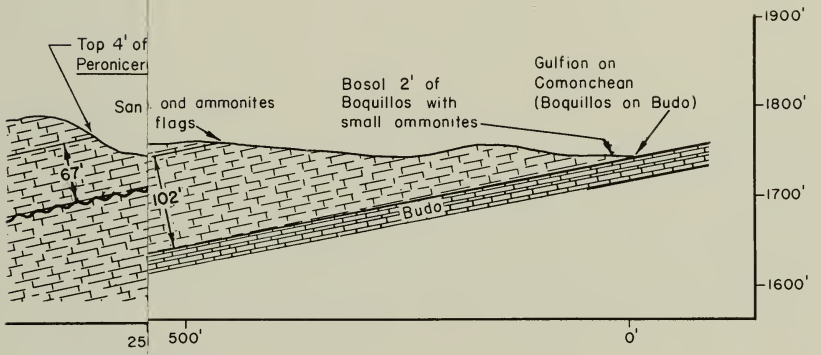
Upper Boquillas section (measured by plane-table), about 1 mile northeast of San Vicente (Pl. VII, no. 23).

	Thickness (Feet)
San Vicente Formation.	
Disconformity.	
Boquillas Formation—	
4. Limestone, gray to slightly brownish gray, almost lithographic, in beds 5 to 18 inches thick. Several limestone beds occur separated at intervals up to 5 feet thick by light-gray, calcareous siltstone in ½- to 2-inch plates.	

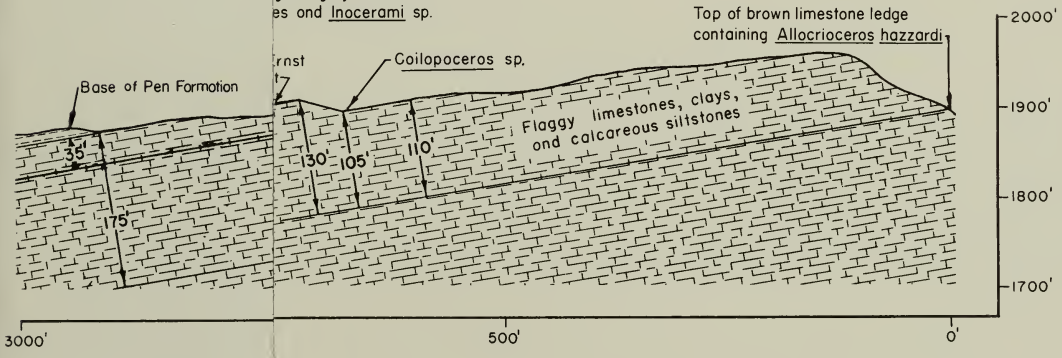
W E

Ernst Member.

San Vicente Member and interval of
nber from top Allocrioceras ledge to
nte.



ge of gray-white chalk
es ond Inocerami sp.



nal Park.

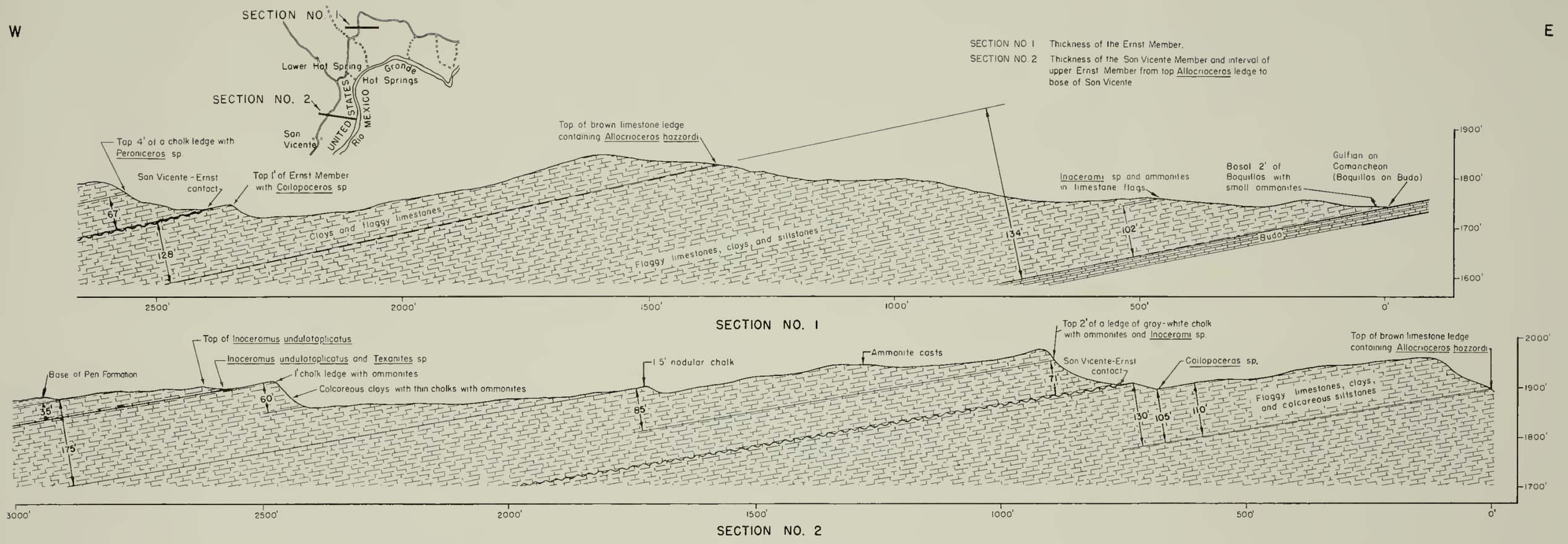


FIG. 37. Planetable profiles of Boquillas Formation (San Vicente and Ernst Members). San Vicente and Hot Springs areas, Big Bend National Park.

	Thickness (Feet)
The unit forms a low cuesta on backslope of a more prominent hogback. *Coilopoceras* sp. in basal 5 feet. Erosion surface at top	20
3. Limestone, gray and slightly brownish gray, almost lithographic in 5- to 18-inch beds. Twenty-four of the limestone beds alternate evenly with light-gray, platy siltstone in 5-foot intervals. These form ¼- to 2-inch plates and a few form 3-inch plates. The unit lies between a hogback and the *Allocrioceras* ledge	110
2. *Allocrioceras* beds. Limestone, brown, case-hardened, siliceous, in 2- to 5-inch beds, interbedded with yellowish-gray and light-brown arenaceous shale in 2-inch beds. *Allocrioceras hazzardi* and other fossils occur	3
Total	133
1. Limestone, gray, buff, flaggy, and interbedded with clay extending to the Rio Grande. Not measured.	

Sierra San Vicente—Mariscal Mountain.—The Ernst Member is exposed in a broad belt bordering the San Vicente—Mariscal uplifts, where it has been deformed by folding, faulting, and igneous intrusion so that the stratigraphic relationships are not everywhere clear. Both *Coilopoceras* and *Allocrioceras* beds occur, and the contact between the Ernst and San Vicente Members is easily recognized except where faulted. The *Allocrioceras* beds border the entire mountain (Pl. II). The *Coilopoceras* beds occur at one locality on the northeastern side of Mariscal Mountain (Pl. II; D, 21) but were not found on the western slopes where there are numerous strike faults. Aside from elimination by faulting, these beds may have been eroded prior to deposition of the overlying San Vicente Member. About 1½ to 3 miles north of the Rio Grande (Pl. II; A–B, 20), the Boquillas Formation is abnormally thin. The rock is most like the San Vicente Member and all the Ernst beds are believed to be absent.

West flank of Sierra del Carmen and Santiago Mountains.—The Ernst Member borders the west flank of these uplifts from near the Rio Grande northward to within a few miles of Persimmon Gap. The *Allocrioceras* beds were mapped from near the river northward to near the northern end of the McKinney Hills (Pl. II; Q, 24). From there northward to near the southern end of Dagger Mountain is a broad area underlain by Ernst but without the *Allocrioceras* beds (Pl. II; Q–T, 22–25). These beds reappear southwest of Dagger Mountain (Pl. II; M, 3) and extend northward beyond Dog Canyon (Pl. II; Q, 3). The *Coilopoceras* beds occur from near the Rio Grande northward for about 3 miles (Pl. II; H, 25), are absent for 25 to 30 miles, and reappear a mile northwest of Dog Canyon (Pl. II; Q, 3). The reason for the absence of the *Allocrioceras* and *Coilopoceras* beds is unknown. Perhaps the Ernst Member was eroded below the *Allocrioceras* beds prior to deposition of the San Vicente Member.

Mesa de Anguila.—The Ernst Member is well exposed along the western slope and locally on top of Mesa de Anguila (Pl. II; H–K, 1–3). It is 200 to 300 feet thick and was deposited on an undulating surface of the Buda. Neither *Allocrioceras* nor *Coilopoceras* beds are preserved, but the *Allocrioceras* beds occur in Mexico. Near the top of the mesa is a thick analcite basalt sill like the sills in the Ernst Member along the western slope of the Sierra del Carmen, the small sills along the west slope of Mariscal Mountain, and those in the Basin-Laguna area.

Christmas Mountains.—The Ernst Member crops out on the flanks of the Christmas Mountains where it has an estimated thickness of 450 feet. The *Allocrioceras* beds are generally prominent but locally are cut out by one or more massive sills. The *Coilopoceras* beds are not recognized.

Basin-Laguna.—A partial Ernst section is exposed along the eastern side of Ward Mountain. The lowermost beds are in contact with the Ward Mountain intrusion; the Buda is not exposed. The *Allocrioceras* beds form a thin interval of steeply dipping, altered beds in the west side of the Basin (Pl. II; L, 15). About 1½ miles farther southeast (west of Laguna), the

Ernst is again in contact with the Ward Mountain intrusion, without fossils.

Fossils and Age

The following megascopic fossils were identified from the Ernst Member in the Park:

Allocrioceras hazzardi Young, 1963
Scipinoceras cf. *S. gracilis* (Shumard, 1860)
Inoceramus labiatus Schlotheim, 1813
Ostrea congesta Conrad, 1843
Coilopoceras sp.
Eutrephoceras sp.
Baculites sp.
Durania sp.
Scaphites sp.
Inoceramus sp.
Hemiaster sp.

The ammonites of the Ernst were studied by W. S. Adkins and R. T. Hazzard and the fossils are listed in table 4 (p. 65). *Inoceramus labiatus* is common and ranges throughout the formation. At least one or more additional species of that genus, one of them large, are also present. *Ostrea congesta* is commonly attached to many of the *Inoceramus* shells. Echinoids, probably *Hemiaster* sp., are common in some beds and *Durania* sp. is sparsely distributed through the formation. Several cephalopods, including *Eutrephoceras* sp. and *Baculites* sp., as well as shark teeth and fish bones, are recognized. The diagnostic ammonites establish at least a partial correlation between the Ernst Member and the Eagle Ford beds in other parts of Texas. Stratigraphic positions of fossils are shown on Plate VIII.

Huffman (1960) studied the microfauna of the Ernst Member and reported 7 families, 13 genera, and 22 species of foraminifera. His collection was made along measured section 21, Plate VII, of this report (Pl. II; J, 25–26), and the list follows:

Ammobaculites subcretaceous Cushman & Alexander, 1930
Globigerina cretacea d'Orbigny, 1840
Globigerina rugosa Plummer, 1927
Globigerina voluta Chapman, 1892
Globorotalia membranacea Ehrenberg, 1854
Globotruncana arca Cushman, 1926
Globotruncana cretacea Cushman, 1936
Globotruncana marginata Reuss, 1845
Globotruncana membanacea Cushman, 1926
Gumbelina moremani Cushman, 1938
Gumbelina nuttalli Voorwijk
Gumbelina pseudotessera Cushman, 1938
Gumbelina reussi Cushman, 1938
Hastigerinella moremani Cushman, 1931
Hastigerinella simplex Morrow, 1934
Lingulina sp.
Neobulimina canadensis Cushman & Wickenden, 1928
Neobulimina irregularis Cushman & Parker, 1936
Planulina eaglefordensis Moreman, 1927
Robulus munsteri Roemer, 1839
Ventilabrella austiniana Cushman, 1938
Virgulina tegulata Reuss, 1845

SAN VICENTE (new) MEMBER

General Features

The Terlingua Beds of Udden (1907a, pp. 33–41) included a lower chalk, a middle soft marly clay, and an upper clay that contains slightly indurated sandstone beds with calcareous concretions. Udden (1907a, p. 40) correlated his lower Terlingua Member with the Austin Chalk of central and northeast Texas and the middle and upper members with the Taylor Marl. Adkins (1933, pp. 270–271, 451–452) distinguished an Austin-age chalk unit in the Big Bend region, placing the top of the *Crioceras (Allocrioceras)* beds at the base of the Austin (about 125 feet below the base of the San Vicente Member as used in this paper). He did not clearly define the upper limit but his description suggests that the top is immediately above the *Inoceramus undulatoplicatus* beds (the top of Udden's lower chalk member and the top of the San Vicente Member in this paper). He placed Udden's middle and upper Terlingua Beds in the Taylor. Later field work indicates that neither of these classifications is entirely satisfactory with respect to lithologic units, age of fossils, and correlation of faunas. In this report, Udden's Terlingua Beds are divided between the San Vicente Member of the Boquillas Formation and the Pen Formation.

The San Vicente Member, as used in this paper, designates a flaggy chalk-marl unit,

TABLE 4.—Thickness of ammonite zones, Cenomanian–Turonian rocks, Presidio County to Dallas County, Texas.

STAGE	Presidio County Tierra Vieja	Brewster County Park area		Brewster County Black Gap area	Brewster County San Francisco Creek	Terrell County Lozier Canyon	Val Verde County Comstock area	Kinney County Brackettville	Bell County Belton	McLennan County Waco area	Dallas County Dallas area
LOWER CONIACIAN	Austin equivalent	San Vicente Member		Austin equivalent	Austin equivalent	Austin equivalent	Austin equivalent	Austin equivalent	Austin equivalent	Austin equivalent	Austin equivalent
TURONIAN	*Coilopoceras*	Ernst Member	*Coilopoceras*	*Coilopoceras*	*Coilopoceras*	*Coilopoceras*	*Coilopoceras*	*Coilopoceras*		*Coilopoceras*	*Coilopoceras*
			Allocrioceras hazzardi	*Allocrioceras hazzardi*							
	Spathites						*Collignoniceras* cf. *C. woollgari*				
	Romaniceras									*Proplacenticeras*	*Proplacenticeras*
	Pseudaspidoceras										
	Fagesia										
						Mammites					
	Kanabiceras				*Kanabiceras*	*Kanabiceras*					*Kanabiceras*
						"*Mantelliceras*"					
CENOMANIAN	*Small desmoceratid ammonites		Small desmoceratid ammonites		Small desmoceratid ammonites	Small desmoceratid ammonites	Small desmoceratid ammonites	Small desmoceratid ammonites	Small desmoceratid ammonites	Small desmoceratid ammonites	
						"*Acanthoceras*"			*Dunveganoceras* cf. *D. pondi*		*Dunveganoceras? Acanthoceras*
	Buda Limestone	Buda Limestone		Buda Limestone	Buda Limestone	Buda Limestone	Buda Limestone	Buda Limestone	Pepper Shale	Pepper Shale	Lewisville Formation
	2,000 feet plus	500 feet plus		200 feet plus	200 feet	200 feet	200 feet	350 feet	125 feet	200 feet	400 feet

* The desmoceratid ammonites may represent more than one zone.

the upper member of the Boquillas Formation. The name is from the old village of San Vicente (Pl. II; G, 25) in Big Bend National Park, which was itself named for Presidio de San Vicente, one of the ancient military outposts built by the Spaniards, probably in the seventeenth century. The Presidio site is a gravel terrace in Mexico, some 50 feet above the Rio Grande, about 2 miles northwest of the now abandoned village on the American side.[5]

The type locality of the San Vicente Member is about 2 miles northeast of the old village (Pl. II; H, 25), immediately east of U. S. Geological Survey benchmark elevation 1,881. The member is mostly 350 to 400 feet thick in Big Bend National Park but locally thins to 130 feet. It is gray, thin- to medium-bedded, chalky and argillaceous limestone flags interbedded with gray or yellowish-gray platy marl or soft gray marl (fig. 38). Some limestone layers are as much as 12 to 18 inches thick, but most beds are only 2 to 6 inches thick. The more calcareous rocks weather grayish white, whereas the more marly beds weather bluish gray or yellowish gray. The San Vicente Member contains more and thicker marl intervals and more chalk than the Ernst Member. The basal 20 feet of the San Vicente is commonly silty or sandy flagstone and locally the basal 6 inches is finely conglomeratic. According to Adkins, the zone of *Peroniceras* sp. is the lowest Austin faunal zone. It is 15 feet above the base of the member in the Agua Fria quadrangle (northwest of the Park) and about 65 feet above the base near San Vicente village but is absent at some places in the Park.

The amount of flagstone decreases upward, and the top of the member is alternating soft gray marl and chalk. The chalk

[5] According to Nelson's (1935–1936) account of Ugaldie's military campaigns in the Big Bend area, the Presidio had been abandoned prior to March 24, 1787. Emory (1857), who surveyed the International Boundary, reported that the structures were in ruins in 1856. Today the only visible remains of the historic site are a few low mounds of adobe and scattered stones.



Fig. 38. Chalky limestone ledges in marl of the San Vicente Member near type locality (Pl. II; H, 25). *Inoceramus undulatoplicatus* beds at top of cuesta.

forms ledges resistant to erosion that frequently stand in low cuestas. A chalky ledge (usually a low cuesta) 15 to 20 feet below the top of the San Vicente contains abundant *Inoceramus undulatoplicatus* and it is shown on the geologic map (Pl. II) by the symbol "xxxx" (fig. 38). Above the *Inoceramus undulatoplicatus* beds as much as 22 feet of gray marl, slightly indurated, with some flagstone, contain numerous large *Inoceramus* sp. In most localities the San Vicente grades upward into the Pen Formation but in places the contact is abrupt (fig. 39).

At several places, especially in the Terlingua area, the uppermost San Vicente Member is shaly, slightly sandy, and dark gray. These dark beds are slightly more resistant to erosion than the gray-white chalk and weather into lenticular mounds, 10 to 20 feet in diameter and 5 to 6 feet high. Johnson (1944) believed these features are of algal reef origin. The mounds photographed by Johnson are probably all below the *Inoceramus undulatoplicatus* beds, but similar mounds occur at the top of the San Vicente elsewhere.

LOCAL FEATURES

San Vicente.—At the type locality of the San Vicente Member is the exposure along the measured section (Pl. II; H, 25) about 1 mile northeast of the abandoned village of the same name. It is 331 feet thick (fig. 35). The basal 6 inches is conglomerate that rests upon the *Coilopoceras* beds of the Ernst Member (Pl. VII, no. 23); above the conglomerate are about 20 feet of gray, buff, and pinkish siltstone, sandstone, argillaceous limestone, and some bentonitic clay with lignite concretions. These are overlain by chalk beds 12 to 18 inches thick, chalky and argillaceous marl, and soft gray marl. The *Peroniceras* beds are not recognized here (fig. 37, no. 2).

The *Inoceramus undulatoplicatus* beds form a 13-foot ledge whose top is 22 feet



Fig. 39. San Vicente—Pen contact near Tornillo Creek about 1 mile south of the McKinney Hills. A, San Vicente Member. B, Pen Formation.

below the top of the member. They are nodular, gray chalk interbedded with platy gray marl. The overlying beds, up to the base of the Pen Formation, are mottled gray and yellowish-brown, finely crystalline limestone interbedded with gray marl, which yielded several large *Inoceramus* sp. that are partly covered with *Ostrea congesta*. Description of the type section follows (Pl. VII, no. 23).

Section of San Vicente Member (measured by planetable), about 1 mile east of the abandoned village (Pl. VII, no. 23).

	Thickness (Feet)
Pen Formation.	
San Vicente Member—	
13. Limestone, dove gray mottled with yellowish-brown streaks, finely crystalline, interbedded with gray marl. Some of the thicker limestone beds contain imprints of large flat *Inoceramus* sp., covered with *Ostrea congesta*. Forms backslope of a low cuesta and underlies the yellowish-gray Pen Formation	22
12. *Inoceramus undulatoplicatus* beds. Limestone, dove gray, fine grained, chalky, in 1-foot beds, interbedded with gray marl in 2½-foot beds. The beds form the crest and upper backslope of the cuesta mentioned above. *Inoceramus undulatoplicatus* is abundant and there are a few *Texanites* cf. *T. texanus*	13
11. Chalk, gray, indurated, forming a ledge, with *Texanites* sp.	1
10. Marl and calcareous clay, dark gray, with small, poorly preserved ammonites and pelecypods	59
9. Limestone and tuff, gray, thin, soft, argillaceous, forming inconspicuous 1-foot ledges, interbedded with shale and marl. Except for the limestone ledges, most of the interval is covered and forms a broad valley between two cuestas	80
8. Limestone, chalky and argillaceous, interbedded with marl. At the top is an 18-inch chalky, nodular limestone ledge. Similar but thinner beds alternate with calcareous clay and marl in the upper 20 feet. The unit also includes a yellowish bentonitic(?) clay seam 6 inches thick. In a 30-foot interval near the middle is flaggy to massive limestone, gray, weathering brown, in 1-foot ledges interbedded with platy, argillaceous limestone. The unit forms a low cuesta and contains ammonite casts and *Inoceramus* sp. The bottom 35 feet is dove-gray, fine-grained, chalky limestone in ledges less than a foot thick, interbedded with platy argillite, forming top of cuesta	85
7. Chalk, dove gray, fine grained, hard, containing molds and casts of ammonites and *Inoceramus* sp.	4
6. Limestone, dove gray, chalky, in 2- to 2½-foot ledges interbedded with yellowish-gray marl. Most of the chalk is in the upper third of the interval and contains molds of ammonites and *Inoceramus* sp. The unit includes the lower slope of the cuesta face above the San Vicente—Ernst contact	46
5. Siltstone, buff, platy, calcareous; most of the plates of above are a fraction of an inch thick. Some beds with thicker plates make a slight ledge	4
4. Limestone, buff, argillaceous	1
3. Sandstone, buff to pinkish, fine grained, platy, in ⅛-inch beds that are more silty upward	15
2. Clay, olive green to yellow, bentonitic, with a concretionary band of lignite and crusts of gypsum	1
1. Sandstone and conglomerate, gray to brownish gray	0.5
Total	331.5
Erosion surface.	
Ernst Member.	

Hot Springs.—About 2 miles north of Hot Springs (Pl. II; J, 25), the San Vicente Member is 393 feet thick, or 47 feet thicker than 3 miles south at San Vicente. Nevertheless, the member is similar at the two localities.

The *Inoceramus undulatoplicatus* beds occur in both places, and the thickness between them and the base of the Terlingua is comparable. Both localities have sandstone and siltstone at the base of the member but the *Peroniceras* beds occur at Hot Springs, whereas they were not recognized near San Vicente. Possibly a substantial thickness of San Vicente, including the *Peroniceras* beds, was deposited in a depression on the Ernst surface in the Hot

Springs area. The section at this locality follows (Pl. VII, no. 23).

Section of San Vicente Member (measured by planetable) about 2 miles north of Hot Springs (Pl. II; J, 25).

		Thickness (Feet)
Pen Formation.		
San Vicente Member—		
9.	Limestone, dove gray streaked with yellow, fine crystalline, in 5- to 6-inch beds, interbedded with gray and buff marl. The limestone beds contain imprints of large flat *Inoceramus* sp. covered with *Ostrea congesta*	18
8.	*Inoceramus undulatoplicatus* beds. Limestone, dove gray and buff, fine grained, chalky, in 1- to 1½-foot beds, interbedded with gray marl in 2-foot beds. The limestone beds contain abundant *Inoceramus undulatoplicatus* and a few *Texanites* cf. *T. texanus*	15
7.	Limestone, gray to buff, chalky, and argillaceous, interbedded with marl and calcareous shale of a similar color. The limestone forms low ridges but most of the surface of the unit is covered by rubble	148
6.	Limestone, yellowish dove gray, chalky, in 12-inch beds, interbedded with buff marl and clay, forming low cuesta	22
5.	Limestone, buff, soft, chalky, thin, interbedded with yellowish-gray marl and clay	87
4.	Limestone, gray, fine grained, argillaceous, in 18-inch beds, interbedded with yellowish-gray marl. Forms a prominent escarpment	36
3.	*Peroniceras* beds. Chalk, dove gray, fine grained forming a ledge	4
2.	Limestone, dove gray, soft, chalky, interbedded with gray marl	43
1.	Clay, yellowish gray, platy, calcareous, silty, sandy in basal few feet	20
	Total	393
Erosion surface.		
Ernst Member.		

Sierra San Vicente—Mariscal Mountain area.—The San Vicente Member crops out in a broad belt along flanks of the San Vicente and Mariscal uplifts (Pl. II; A–E, 19–23) where it is much like the two areas previously described. Here the member is 350 to 400 feet thick but was not measured.

The *Inoceramus undulatoplicatus* beds, as well as the *Peroniceras* beds, occur north of the higher elevations of Sierra San Vicente (Pl. II; E, 23). The San Vicente Member is complexly folded, commonly faulted, and deformed by intrusion along most of the flanks of Mariscal Mountain. The *Inoceramus undulatoplicatus* beds are prominent on the east side of the uplift (Pl. II; D, 21), about a mile west of the old Solis ranch; *Peroniceras* sp. was collected about a mile farther south. The *Inoceramus undulatoplicatus* beds occur along most of the western flank of the uplift, where *Texanites* cf. *T. texanus* and *Peroniceras* sp. were not recognized. Beds with well-preserved *Inoceramus undulatoplicatus* (fig. 40) crop out near the Rio Grande on the flank of a small anticline 2½ to 3 miles west of the head of Mariscal Canyon (Pl. II; A, 20).

West side of Sierra del Carmen.—The San Vicente Member forms a nearly continuous band along the western border of the Sierra del Carmen and crops out in isolated areas as far north as Persimmon Gap west of the Santiago Mountains but is much faulted. Some fossil zones can be traced north from the Rio Grande, including that of *Inoceramus undulatoplicatus* shown on the map (Pl. II). Well-preserved individuals of that species associated with *Texanites* sp. occur along the southeastern flank of the McKinney Hills as well as near Muskhog Spring (Pl. II; S, 22). The uppermost San Vicente beds are exposed along the western flank of the McKinney Hills intrusive, but the *Inoceramus undulatoplicatus* beds were not definitely located. *Peroniceras* sp. was collected northward as far as midway between the Rio Grande and the south end of the McKinney Hills. The San Vicente Member thins northward so that west of Dog Canyon (Pl. II; Q, 2) it is only 130 feet thick.

Christmas Mountains.—A broad band of the San Vicente Member borders the Christmas Mountains (Pl. II; Q–R, 12–13) where it is highly folded, faulted, and deformed by crosscutting intrusive masses. The *Inoceramus undulatoplicatus* beds are conspicuous at several localities and



FIG. 40. *Inoceramus undulatoplicatus*, commonly found 15 to 20 feet below top of the San Vicente Member.

can be traced around most of the uplift. The member is about 350 feet thick.

Chisos Mountains.—Highly deformed rocks of the San Vicente Member containing *Inoceramus undulatoplicatus* crop out along the west side of the Basin and west of Laguna in the Chisos Mountains, where they were elevated by the Ward Mountain intrusion.

FOSSILS AND AGE

The following fossils were collected from the San Vicente Member:

Inoceramus undulatoplicatus Roemer, 1852
Inoceramus cf. *I. subquadratus* Schüter, 1887
Haploscapha grandis Conrad, 1875
Ostrea congesta Conrad, 1843
Texanites cf. *T. texanus* Roemer, 1852
Durania austinensis Roemer, 1847
Peroniceras sp.
Texanites sp.
Baculites sp.
Inoceramus spp.
Hemiaster sp.

Fossils are numerous in several beds at some places in the San Vicente. The ammonite *Peroniceras* sp. is characteristic of beds near the base, and *Inoceramus undulatoplicatus* and *Texanites* cf. *T. texanus* are abundant in a ledge about 20 feet below the top. *Haploscapha grandis*, *Inoceramus* cf. *I. subquadratus*, and *Ostrea congesta* are present but their occurrence is not sufficiently abundant or persistent to constitute fossil zones. *Durania austinensis* is sparsely distributed throughout the formation and some *Baculites* sp. and *Hemiaster* sp. occur. Fish bones, shark teeth, and mosasaur remains are also present. The fossils of the San Vicente Member indicate an Austin age, and fossil zones are summarized on Plate VIII.

Bostik (1960) collected foraminifera from the San Vicente Member near the type locality (Pl. II; G–H, 25) and listed the following species:

Ammobaculites fragmentarium Cushman, 1927
Bolivinita planata Cushman, 1927

Bolivinitella eleyi Cushman, 1946
Brachycythere sphenoides Reuss, 1854
Buliminella carseyae Plummer, 1931
Buliminella cushman Sandidge, 1932
Chrysalogonium cf. *C. texanum* Cushman, 1936
Cythereis cf. *C. austinensis* Alexander, 1929
Cythereis bicornis Israelsky, 1929
Cythereis dallasensis Alexander, 1929
Cytherella austinensis Alexander, 1929
Dentalina gracilis (d'Orbigny, 1840)
Dentalina intrasegma Carsey, 1926
Dorothia cf. *D. alexanderi* Cushman, 1936
Dorothia cf. *D. bulletta* (Carsey, 1926)
Dorothia stephensoni Cushman, 1936
Ellipsoidella gracillima Cushman, 1933 (Frizzell, 1954)
Eouvigerina plummerae Cushman, 1933
Flabellammina clava Alexander & Smith, 1932
Frondicularia austiniana Cushman, 1936
Frondicularia cordata Roemer, 1941
Gaudryina (Gaudryina) rudita Sandidge, 1932
Gaudryina (Siphogaudryina) austinana Cushman, 1946
Globigerina rugosa Plummer, 1927
Globigerina saratogaensis Frizzell, 1954
Globigerinella aissana Sigal, 1952
Globorotalia cushmani Morrow, 1934
Globorotalites umbilicatus Loetterle, 1937
Globotruncana arca Cushman, 1927
Globotruncana arca var. *contusa* Cushman, 1926
Globotruncana canaliculata (Reuss, 1845)
Globotruncana fornicata Plummer, 1931
Globotruncana marginata (Reuss, 1845)
Globulina lacrima var. *lacrima* Reuss, 1845
Gumbelina globocarinata Cushman, 1938
Gumbelina moremani Cushman, 1946
Gumbelina plummerae Loetterle
Gumbelina pseudotessera Cushman, 1938
Gumbelina reussi Cushman, 1938
Gumbelina striata (Ehrenberg, 1838)
Gyroidina depressa Alth, 1850
Gyroidina girardana (Reuss, 1851)
Gyroidina globosa (Hagenow, 1842)
Hastigerinella alexanderi Cushman, 1931
Hastigerinella moremani Cushman, 1931
Hastigerinella simplex Morrow, 1934
Hastigerinella watersi Cushman, 1931
Lenticulina rotulata Lamarck, 1804
Loxostumum cushmani Wickenden, 1932
Kyphopyxa christneri Carsey, 1926
Marginulina austiniana Cushman, 1937
Marginulina directa Cushman, 1937
Marssonella oxycona (Reuss, 1880)
Neobulimina caradensis Cushman & Wickenden, 1928
Neobulimina irregularis Cushman & Parker, 1936
Neoflabellina cushman Morrow, 1934
Neoflabellina hebronensis Moreman, 1927
Neoflabellina suturalis Cushman, 1936
Nodosaria affinis Reuss, 1845
Nodosaria distans Reuss, 1858
Nodosaria sp.
Palmula pilulata Cushman, 1938
Paracypris angusta Alexander, 1929
Planulina arimensis Morrow, 1927
Planulina austiniana Cushman, 1938
Planulina eaglefordensis Alexander, Howe & Laurencich, 1958
Planulina kansasensis Morrow
Planularia cf. *P. dissona* (Plummer, 1931)
Pleurostomella austiniana Cushman, 1933
Pleurostomella watersi Cushman, 1933
Pseudofrondicularia undulosa Cushman, 1936
Pterygocythere cf. *P. saratogana* Israelsky, 1929
Rectogumbelina texana Cushman, 1932
Robulus munsteri Roemer, 1839
Robulus taylorensis (Plummer, 1931)
Saracenaria triangularis d'Orbigny, 1840
Siderolites sp.
Spiroplectammina laevis var. *cretosa* Cushman, 1932
Spiroplectammina lalickeri Albritton & Phleger, 1937
Ventilabrella austiniana Cushman, 1929
Virgulina tegulata Reuss, 1845
Vitriwebbina biosculata Frizzell, 1954

Pen (New) Formation

GENERAL FEATURES

The term Pen Formation as here proposed is used to designate a lithostratigraphic unit that includes Udden's (1907a, pp. 33–41) middle and upper members of his Terlingua Beds and the unit called Terlingua equivalent by Adkins (1933, pp. 270–271, 451–452). It is named from Chisos Pen north of the Chisos Mountains (Pl. II; O, 12–13).

The Pen Formation is 219 to about 700 feet thick in the Park. Its total thickness is readily determined but because of the extensive alluvial cover it is usually difficult to determine individual units. The basal 50 feet is normally calcareous clay, light bluish gray, with 1-inch beds of gray chalk (fig. 41). Above this is yellow clay with scattered sandy beds in which some concretions are in beds and others are irregularly distributed. The top clay is sandy and there are beds of sandstone up to 5 feet thick at some places. All the rocks weather yellow or yellowish gray. The formation is soft and less resistant to erosion than either the San Vicente below or the Aguja above, and it forms a belt of low topog-



Fig. 41. Basal Pen Formation with gray chalk layers, southwest flank of the Christmas Mountains.



Fig. 42. Pen Formation near the type locality at Chisos Pen (Pl. II; O, 12).

raphy (fig. 42). Badlands occur in some places but where indurated terrace gravels cap the clay, it stands in steep-faced slopes (fig. 43) and some of its unprotected surfaces are low and are subject to sheet wash (fig. 44).

Concretions are common throughout, most of which are calcareous, although some are clay-ironstone. Most of the concretions are disc-shaped and are as much as 4 feet in diameter. Most of them are scattered in the clay, but some form layers which extend for several miles (fig. 45). Many of the concretions are cracked and filled with siltstone or thin bands of dark calcite. Layers with numerous concretions are mostly sandy and commonly the concretions are encrusted by sandstone. Many of them contain large ammonites and pelecypods, and smaller fossils occur in the adjacent sandy clay.

LOCAL FEATURES

San Vicente—Hot Springs area.—The Pen Formation is 457 feet thick (by planetable) 2 miles north of Hot Springs (Pl. II; J, 25). Both base and top are exposed but most of the beds are covered. The base is gray calcareous clay, mostly covered, lying 18 feet above the *Inoceramus undulatoplicatus* beds in the San Vicente. The top is a gray clay with *Exogyra ponderosa* that terminates at the base of a 20-foot-thick, yellowish-gray sandstone ledge of the basal Aguja. The most conspicuous stratigraphic unit is a 40-foot-thick interval containing concretions with abundant ammonites, pelecypods, and gastropods. The base of the concretion-bearing interval is 310 feet above the base of the formation and the concretionary beds occur at other localities. The following stratigraphic section was measured.

Type section of Pen Formation (measured by planetable) about 2 miles north of Hot Springs (Pl. VII, no. 21).

	Thickness (Feet)
Aguja Formation.	
Unconformity.	
Pen Formation—	
4. Clay, yellowish gray and yellow, with *Exogyra ponderosa*	20



FIG. 43. Outcrop of Pen Formation beds capped by indurated gravel terrace in steep-faced slope along Terlingua Creek.



FIG. 44. Flat of soft yellow Pen Formation in Terlingua Creek valley. (Photograph by Peter Koch.)



FIG. 45. Concretions in the Pen Formation along Tornillo Creek west of the McKinney Hills.

	Thickness (Feet)
3. Clay, yellowish gray and yellow, mostly covered. In one arroyo east of Tornillo Creek, *Exogyra ponderosa* is abundant	87
2. Clay, soft, yellow, with three sandy layers containing septarian concretions as much as 4 feet across. The concretions and sandy layers nearby are fossiliferous. Most of the fossils are not well preserved, but according to W. S. Adkins, R. T. Hazzard, and J. T. Twining, they include *Placenticeras* cf. *P. placenta, Placenticeras* sp., *Delawarella delawarensis, Eutrephoceras dekayi, Exogyra ponderosa, Exogyra upatoiensis, Veniella conradi, Trigonia* aff. *T. bartrami, Cyprimeria* cf. *C. gabbi, Inoceramus* sp., *Lima* sp., *Ostrea(Lopha) falcata, Ostrea* sp., *Turritella* cf. *T. quadrilira, Volutomorpha*-type gastropods, *Baculites* sp., and *Serpula cretacea*	40
1. Clay, soft, yellow, mostly covered	310
Total	457

San Vicente Member—
Gray chalk.

A mile northeast of San Vicente (Pl. II; H, 25) the Pen Formation is 425 feet thick. It underlies a barren flat that formerly was used for landing small aircraft. The basal part is gray clay that begins 22 feet above the *Inoceramus undulatoplicatus* beds in the San Vicente. The base of the Aguja is a yellowish-brown sandstone 30 feet thick north of the old landing strip. The uppermost 20 feet of the Pen Formation is a yellowish-gray clay with thin sandy beds containing *Exogyra ponderosa, Placenticeras* cf. *P. placenta, Eutrephoceras dekayi.* and *Inoceramus* sp. The rest of the section is mostly debris covered (Pl. VII, no. 23).

The Pen Formation crops out in the crest of the San Vicente anticline northwest of San Vicente (Pl. II; G–J, 22–24). The top sandy clay ends abrupty beneath a sandstone ledge in the Aguja Formation. A concretionary layer, in which fossils are a conspicuous part of the rock, occurs 40 to 50 feet below the Aguja. The most common fossils are *Exogyra ponderosa, Placenticeras* cf. *P. placenta, Delawarella delawarensis, Trigonia* cf. *T. bartrami, Turritella* cf. *T. quadrilira,* and several unidentified species of pelecypods and gastropods.

Sierra San Vicente—Mariscal Mountain—Cow Heaven anticline.—Isolated outcrops of the Pen Formation form a low belt bordering the northern end of Sierra San Vicente (Pl. II; E–F, 22–23) and surround Mariscal Mountain (Pl. II; A–F, 19–22). The upper Pen forms the crest of the Cow Heaven anticline (Pl. II; E–G, 17–18). The formation is chiefly yellow clay, but near intrusions it is baked and altered to yellowish-brown or black hornfels. Many of the exposures are faulted, are extensively covered by alluvium, and no planetable measurements were attempted.

On the east side of Mariscal Mountain, a mile north of the old Solis ranchhouse (Pl. II; D, 22), scattered outcrops of the Pen Formation occur over an area of a square mile and the section is about 400 feet thick. A concretion bed 100 feet below the base of the Aguja crops out near one of the roads that lead to the old ranchhouse. In the concretionary beds are the usual ammonites, pelecypods, and gastropods. The formation is exposed in many places on the west side of Mariscal Mountain. West of Mariscal mine (Pl. II; E, 19), the clay has been altered to dark hornfels, the large concretions are numerous, but only fragments of pelecypods and ammonites were found. Farther south near structure section E–E′ (Pl. II), concretionary layers are 75 feet below the base of the Aguja and pelecypods, ammonites, and gastropods are an important part of the rock constituents. The section is about 450 feet thick. About 200 feet of the Pen Formation crops out along the crest of the Cow Heaven anticline (Pl. II; F, 17). The concretionary layer in yellow clay is about 60 feet below the base of the Aguja and contains the fossils commonly found associated with the concretions.

McKinney Hills.—The Pen Formation crops out on all sides of the McKinney Hills except the north. Both upper and



Fig. 46. Pen Formation at Banta Shut-In; the rock has been altered to black hornfels by the McKinney Hills intrusion. This material was used by the Indians for making tools (Pl. II; N, 23). (Photograph by J. T. Twining.)

lower contacts are exposed along the west side, but the intrusion crosscuts the formation and the upper beds are absent along the east flank. Most beds have been baked and in the vicinity of Banta Shut-In they are altered to black hornfels (fig. 46). There is less alteration away from the intrusion where the colors are yellowish brown to gray.

The Pen Formation is well developed on the west side of Tornillo Creek about a mile north of Banta Shut-In (Pl. II; O, 23). Here it is dark-gray shale, slightly baked, which dips 10° to 12° away from the intrusion. Both the base and top of the formation are exposed, and although the beds have been deformed no beds seem to be omitted or repeated. The formation is 572 feet thick, according to a hand-level—pacing measurement, or 115 feet thicker than north of Hot Springs. Large concretions occur throughout the sequence and have a greater vertical range than in the Hot Springs—San Vicente or the Mariscal Mountain areas. No ammonites were found but numerous pelecypods and gastropods were collected from a concretionary interval 40 to 50 feet thick beginning 375 feet above the base.

Farther north of Banta Shut-In (Pl. II; P, 22) the Pen Formation dips 35° at the base and flattens to 3° near the top. Within the exposure is a small anticline subsidiary to the McKinney Hills uplift in which the beds dip from 6° to 30°. A hand-level measurement here indicates a thickness of 390 feet (Pl. VII, no. 20), and the Pen Formation has thinned appreciably northward in a distance of 2 to 3 miles. The dark-gray Pen clay and chalk beds lie on the San Vicente Member and are overlain and beveled by the basal Aguja Formation. The upper 30 feet of the Pen Formation is sandy and contains some sandstone beds, mostly 2 to 3 feet thick. These are best exposed in the east bank of Tornillo

Creek along the drainage parallel to the line of measured section (Pl. II, no. 20). The remainder of the formation is slightly baked, yellowish-brown to gray clay with concretions. These are most numerous in the middle part of the formation but are nonfossiliferous. Immediately beneath the Aguja, about half a mile north of the measured section (Pl. II; P, 22), is a ledge of concretions with abundant ammonites, pelecypods, and gastropods. The ledge appears to have been eroded from the measured section (Pl. II, no. 20), and it probably correlates with concretionary layers in the Hot Springs—San Vicente—Mariscal Mountain—Cow Heaven anticline areas.

Farther north, on the northwest flank of the McKinney Hills (Pl. II; O, 22), the Pen Formation is 219 feet thick (measured by planetable) (Pl. VII, no. 19). Here it is a dark-gray, slightly baked clay that rests on the San Vicente. The top is unconformable beneath the basal sandstone ledge in the Aguja. The uppermost beds are sandy and one sandstone ledge, 5 feet thick, is 25 feet below the top. Concretions are not common except in a thin layer immediately above the 5-foot sandstone ledge but this layer is unlike the fossiliferous concretionary beds at other localities. Apparently 200 to 300 feet of the upper Pen Formation was eroded, including the fossiliferous concretionary beds, from this area.

Chisos Pen.—The Pen Formation (at the type locality) crops out along the crest of a faulted anticline west of Chisos Pen (Pl. II; N–O, 12). Its base is exposed along Cottonwood Creek near where it crosses the Burro Mesa fault. The formation is 634 feet thick (Pl. VII, no. 16). The basal 125 feet is blue-gray clay where fresh, weathering yellow. It contains a few concretions, usually not more than 12 to 18 inches across, and there are a few fossil fragments. Above the basal unit are yellowish-gray and yellow clays that underlie the flat north of Cottonwood Creek (fig. 42). The clay contains concretionary layers that are fossiliferous. An ammonite aptychi found in the upper Pen beds exposed in this area was not found in the beds exposed farther east. This aptychi also occurs in the Pen beds that are exposed in the Study Butte area but absent in the eastern and southeastern parts of the Park.

Christmas Mountains.—The Pen Formation forms a low belt bordering the Christmas Mountains on the south and southeast. It is mostly yellowish clay, but adjacent to intrusions it is brown hornfels. The Christmas Mountains structure is complex but the Pen is probably about 300 to 400 feet thick. Concretionary beds about 50 feet below the Aguja are well developed about 3 miles southwest of Smallpox Well. Scattered fragments of ammonites and pelecypods occur but no definite fossil beds were noted.

Study Butte.—On Dawson Creek, about a mile south of Study Butte (Pl. II; M–N, 9), the Pen Formation is about 700 feet thick. Most of the lower middle part of the sequence is covered. About 20 feet of bluish-gray, calcareous clay, 300 feet above the base of the sequence, crops out in a small, steep-faced, gravel-capped ridge on the northeast side of the old Study Butte road. Here there is a dwarf fauna of pelecypods, gastropods, and ammonites that has been studied and identified by Keith Young (personal communication, March 12, 1963). This dwarf fauna was found at most places in the Study Butte area but has not been found farther east. The same species of ammonite aptychi found at Chisos Pen also was noted in these beds and at other places near Study Butte. About 250 feet above the dwarf fauna beds is an interval of concretions that contains numerous specimens of ammonites, pelecypods, and gastropods. The uppermost part of the Pen is a dark-gray clay that underlies the Aguja Formation. Similar sections of the Pen Formation, with fossiliferous concretionary beds, crop out northeast and north of Maverick Mountain, southeast of Leon Mountain, west of Rattlesnake Mountain, and west of Terlingua Abaja.

Measured sections (Pl. VII) of the Pen Formation demonstrate variation in thick-

ness. There is a general increase from about 400 to 450 feet in the Hot Springs-San Vicente area to about 700 feet near Study Butte. Although there are many local variations, the Pen Formation generally thickens from southeast to northwest across the Park. At least part of the thickness change is due to pre-Aguja erosion, but the amount of pre-Aguja erosion in most places is probably not equal to the difference between the minimum and maximum thickness of the Pen Formation.

FOSSILS AND AGE

The following fossils were identified from the Pen Formation:

Exogyra ponderosa Roemer, 1852
Exogyra upatoiensis (Morton, 1833)
Veniella conradi Stephenson, 1923
Cyprimeria cf. *C. gabbi* Stephenson, 1923
Ostrea congesta Conrad, 1843
Placenticeras cf. *P. placenta* Dekay, 1828
Placenticeras sp. juv. cf. *P. meeki* Bohm, 1898
Submortoniceras sp. juv. cf. *S. mariscalensis* Young, 1963
Delawarella delawarensis (Morton, 1830)
Texanites cf. *T. texanus* Roemer, 1852
Eutrephoceras dekayi (Morton, 1833)
Durania terlinguae Roemer, 1852
Spinaptychus sternbergi Fischer & Fry, 1953
Trigonia cf. *T. bartrami* Stephenson, 1923
Turritella cf. *T. quadrilira* Conrad, 1860
Exogyra sp.
Inoceramus sp.
Cyprimeria sp.
Placenticeras sp.
Delawarella sp.
Baculites sp.
Scaphites sp.
Trigonia sp.
Turritella sp.
Tylostoma sp.

Of the fossils common to the Pen Formation, *Exogyra ponderosa* is the most abundant. It ranges from the base of the formation into the Aguja. It is especially abundant in the concretionary beds, and at one place in the north bank of Tornillo Creek, about a mile above the lower bridge, it is an important rock constituent in a 10-foot interval. *Exogyra upatoiensis* was not found below the concretionary beds but ranges upward into the Aguja.

Placenticeras cf. *P. placenta* and *Delawarella delawarensis* are the most abundant ammonites. *Placenticeras* ranges throughout the formation, but *Delawarella* appears to be limited to the upper half and the first abundant occurrence is in the concretionary beds. *Texanites* cf. *T. texanus* is not common and is apparently limited to the lower half of the formation. *Eutrephoceras dekayi* and most of the pelecypods and gastropods in the concretions are found throughout the Pen Formation and most of them range upward into the Aguja.

Durania terlinguae is scarce and its range is probably limited to the Pen. Specimens were found north of Hot Springs, at Chisos Pen, Dawson Creek, and north of Study Butte. *Ostrea congesta* occurs at all levels; shells are commonly attached to the large pelecypods and ammonites, and occasionally they are preserved on the outer layers of the concretions. *Inoceramus* shell fragments are widely distributed and locally very abundant. Some species are extremely large and fragments 2 feet or more across have been noted.

The dwarf fauna found in the Study Butte area is a distinctive stratigraphic marker. In the measured section south of Study Butte (Pl. II; M, 9), these beds are 420 feet below the top of the formation. The most abundant species are *Placenticeras* sp. juv. cf. *P. meeki*, a black, tightly coiled form with complex suture pattern about the size of a 50-cent piece, and a black, shiny *Baculites* sp. Associated with dwarf fauna are ammonite aptychi from *Spinaptychus sternbergi*. Their outer surfaces have irregularly distributed pitted tubercles and pustles and the inner surface is marked by distinct growth lamellae.

The Pen faunal assemblage suggests an upper Austin age. The Pen correlates with the lower Anacacho and Upson in the Anacacho Mountains, the Dessau Chalk in the Austin area, some part of the Austin section above the hiatus described by McNulty (1955) in northeast Texas, and to some part of the Brownstown Marl in northeast Texas, Louisiana, and Arkansas.

Aguja Formation

GENERAL FEATURES

The Aguja Formation was originally named Rattlesnake Beds by Udden (1907a, pp. 41–54), but as the name Rattlesnake was preoccupied, Adkins (1933, p. 505) substituted the term Aguja, named for Sierra Aguja (Needle Peak) (Pl. II; K, 5). The Sierra Aguja is about 5 miles from the original locality at Rattlesnake Mountain; the formation crops out on the lower slopes beneath a capping of Tertiary volcanic rocks. The Aguja is preserved in the Big Bend (Chisos Mountains and Terlingua quadrangles), Brewster County; the San Carlos—Candelaria—Presidio area, Presidio County; and in adjacent parts of Chihuahua, Mexico.

The Aguja Formation everywhere lies unconformably on the Pen Formation. The base is a sandstone ledge, 5 to 35 feet thick, which is mostly yellowish gray, yellow, or yellowish brown (fig. 47). The basal sandstone normally forms a ridge 10 feet or more high and is commonly conglomeratic at the base, especially in the eastern half of the Park. Although the basal Aguja is always a sandstone resting on an eroded Pen surface, it probably is not everywhere the same age.

The second unit of the Aguja Formation is a fossiliferous marine clay of variable thickness and character. It is mostly gray or dark gray, silty, or sandy clay that weathers yellow or yellowish brown. In places it is calcareous and looks much like the Pen Formation except that it is more sandy and contains thin sandstone lenses. It varies from 175 feet thick near San Vicente to more than 500 feet north of Tule Mountain (Pl. II; M, 10). At Chisos Pen (Pl. II; P, 13) the basal 200 feet of clay of other localities is mostly replaced by sandstone (Pl. VII). The clay contains concretions up to 3 or 4 feet in diameter; some are in layers and others are irregularly scattered through an interval 50 feet thick



FIG. 47. Basal Aguja sandstone near San Vicente. The Aguja-Pen contact is commonly covered by debris from above.



Fig. 48. Sandstone and clay in the Aguja Formation near San Vicente. Note the concretion in upper center and broken concretion at lower left.



Fig. 49. Ironstone concretion, 3 feet in diameter, in upper center of figure 48.

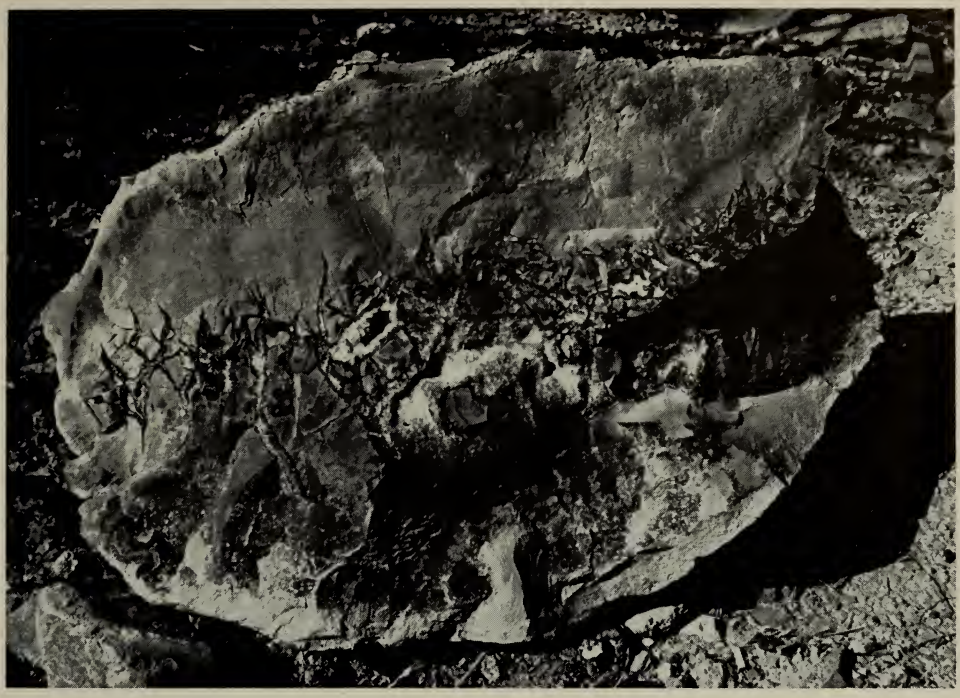


FIG. 50. Calcite veins in broken ironstone concretion, lower left of figure 48.

(figs. 48–50). Most of the concretions are reddish-brown ironstone and differ from the calcareous concretions found in the Pen.

The clay unit is overlain by sandstone which is the base of a sequence of alternating marine sandstone and clay beds that grade upward into the nonmarine rock. The nonmarine Aguja is continental detritus, lacustrine and lagoonal, as much as 880 feet thick (Pl. VII, nos. 18 and 19). The rocks are (1) yellowish-gray, yellow, and brown, dirty, argillaceous, platy, ripple-marked, cross-bedded sandstone (fig. 51); (2) greenish-gray, yellow, yellowish-brown, and purple clay with calcareous nodules; (3) calcareous clay; (4) small amounts of fresh-water limestone; and (5) dark carbonaceous clay with thin lignite seams. There is an irregular alternation of the sandstone and clay units; the carbonaceous clays, lignite beds, and fresh-water limestones occur locally at different levels. Most of the sandstone layers are cross-bedded and some are ripple marked. Fossils include dinosaur bone, turtle remains, and silicified wood. Most of the uppermost clay is identical in color and similar in lithology with the overlying Javelina Formation. The contact is placed at the top of a sandstone above which the beds are predominantly varicolored bentonitic clay.

Conspicuous intrusions lie within the Aguja at many places. Most of them are sills or thick tabular masses and some cover an area of several square miles. The clay beds near the intrusion are commonly baked and some are altered to hornfels. The colors are frequently brighter near the intrusions, which adds to the difficulty of distinguishing between Aguja and Javelina clay beds unless they are fossiliferous. Some of the intrusions were emplaced in the late Mesozoic, were earlier than most of the igneous rock in the Park, and were deformed in late Cretaceous time.

LOCAL FEATURES

San Vicente area.—The Aguja Forma-



FIG. 51. Beds of nonmarine Aguja sandstone. Similar sandstone ledges protrude through alluvium at many places west of Mariscal Mountain, north of Talley Mountain, and north of San Vicente.

tion crops out in a broad belt north and northwest of San Vicente (Pl. II; G–H, 24–25). The base is yellow and yellowish-gray marine sandstone, 30 feet thick, that forms a ridge projecting 10 feet or more above the Pen Formation. This is overlain by 175 feet of yellowish marine clay, some of which resembles the Pen Formation but is more sandy. This is succeeded by 140 feet of marine sandstone and clay that grade upward into nonmarine beds. Because of low dip and extensive alluvial cover, the Aguja-Javelina contact could not be accurately located. The following section gives lithologic detail and location of fossils.

Partial Aguja section (measured by plane-table), north of San Vicente (Pl. VII, no. 23).

	Thickness (Feet)
Javelina Formation.	
Gradational contact?	
Aguja Formation—	
Nonmarine beds	
40. Clay, yellow, and thin sandstone beds, mostly covered; not measured.	
39. Sandstone, yellowish gray and reddish gray, argillaceous	10
38. Clay, yellowish gray and reddish mottled, sandy	25
37. Sandstone, red, cross-bedded, conglomeratic at base, with dinosaur bones	12
36. Clay, yellow, sandy, with dinosaur bone 7 feet below top	19
35. Sandstone, brown	7
34. Clay, yellowish gray	10
33. Sandstone, yellowish brown	13
32. Clay, yellow, sandy	30
31. Sandstone, red and gray, cross-bedded, with molds and casts of marine(?) pelecypods	13
30. Clay, gray and maroon mottled	22
29. Sandstone, reddish, cross-bedded	5
28. Clay, gray, yellowish gray, and dark gray	68
27. Sandstone, yellowish brown, with dinosaur bone fragments	5
26. Clay, gray and yellow mottled, with thin sandstone beds	32
25. Sandstone, yellowish brown	5
24. Clay, yellowish gray	8
23. Sandstone, brownish	5
22. Clay, gray, mottled with yellow and	

		Thickness (Feet)
	pinkish, and thin sandstone beds containing fossil tree trunk, 29 feet long, 2 feet diameter at base, with 26 visible growth rings	13
21.	Sandstone, gray	12
20.	Clay, gray and maroon mottled, with a few sandstone beds 1 to 5 feet thick	88
19.	Sandstone, gray to yellowish brown	5
18.	Clay, gray and pinkish mottled	12
	Approximate top of marine beds	
17.	Sandstone, yellowish brown	20
16.	Clay, yellowish gray	14
15.	Sandstone, yellowish brown	5
14.	Clay, yellowish gray	7
13.	Sandstone, yellowish gray, fossiliferous, with *Cardium* sp. and a large gastropod (*Tylostoma* sp.)	15
12.	Clay, yellowish gray	8
11.	Sandstone, yellowish, cross-bedded, with marine fossils (*Exogyra* sp.) and fossil wood fragments	12
10.	Clay, yellowish gray	13
9.	Sandstone, yellowish	6
8.	Clay, yellowish gray	14
7.	Coal bed	3
6.	Clay, gray, with agatized wood fragments	7
5.	Sandstone, reddish and gray, cross-bedded	15
4.	Clay, gray and dark gray	100
3.	Clay, gray, calcareous, with disc-shaped concretions, 1 × 2 × 3 feet in size, and *Exogyra ponderosa*	50
2.	Clay, gray and yellowish gray	25
1.	Sandstone, yellow and yellowish gray, calcareous, with concretions up to 18 inches in size, *Placenticeras* sp., *Exogyra ponderosa*, and molds and casts of other pelecypods	30
	Total	763

Unconformity.
Pen Formation.

McKinney Hills.—The Aguja Formation crops out in a narrow belt on the west and northwest sides of the McKinney Hills uplift. The beds are deformed and locally are tilted as steeply as 45°. The base is a marine sandstone, slightly altered, which locally includes one coal seam and rests unconformably upon the Pen Formation. Most of the shale is slightly baked, some of it is dark gray or black, and several carbonaceous layers occur. A composite section measured on the northwest side of the uplift is 1,171 feet thick (Pl. II; Q, 22). Lithologic descriptions follow (Pl. VII, nos. 18 and 19).

Composite section (measured by planetable), northwest flank of McKinney Hills (Pl. VII, nos. 18–19).

		Thickness (Feet)
Javelina Formation.		
Gradational contact.		
Aguja Formation—		
	Nonmarine beds	
31.	Sandstone, gray, cross-bedded, with clay-ball conglomerate	25
30.	Clay, gray or mottled with maroon, with thin, poorly indurated sandstone ledges. One clay bed near base contains clay-ball pebbles	102
29.	Sandstone, gray, massive, forming a ledge	22
28.	Clay, gray, greenish-gray mottled, with thin beds of soft, silty sandstone	81
27.	Sandstone, massive, gray, forming a ledge	17
26.	Clay, gray and greenish gray	126
25.	Sandstone, red and gray, massive, cross-bedded, forming a ledge	23
24.	Clay, gray and maroon, with grayish, calcareous nodules	83
23.	Sandstone, red, platy	5
22.	Clay, gray and maroon, with greenish-white, calcareous nodules	72
21.	Sandstone, gray, cross-bedded	12
20.	Clay, gray and maroon mottled, with some sandstone beds as much as 5 feet thick	108
19.	Sandstone, yellowish gray and brownish	10
18.	Clay, gray and maroon mottled, with thin beds of argillaceous sandstone	102
17.	Sandstone, yellowish gray, soft, with incomplete dinosaur skeleton	10
16.	Clay, gray	2
15.	Sandstone, gray, poorly cemented, with dinosaur bones	6
14.	Clay, gray	4
13.	Sandstone, gray, thin bedded, soft, with dinosaur bones	4
12.	Clay, gray, sandy, with fossil tree trunk at base	4
11.	Clay, gray, with thin sandy beds as much as 2 feet thick	65
	Approximate top of marine beds	
10.	Sandstone, gray, platy, with molds and casts of marine pelecypods and gastropods	5
9.	Clay, yellowish gray and yellow	18
8.	Clay, gray, containing large reddish concretions, 2 × 3 × 4 feet in size	4

		Thickness (Feet)
7.	Clay, yellowish gray	40
6.	Clay, gray, containing large reddish concretions, 2 × 3 × 4 feet in size	5
5.	Clay, yellowish gray	42
4.	Clay, gray, calcareous, containing brownish-gray and yellowish-gray concretions, 1 × 2 × 3 feet in size, with cone-in-cone structure. *Exogyra ponderosa* and *Placenticeras* sp. occur in concretions. Fragments of fossil palm wood and two palm fronds occur in sandy beds near base of unit	72
3.	Clay, dark gray, fossiliferous, with fossil pelecypod reef 6 inches thick, about 5 feet below top	70
2.	Clay, black, calcareous, with *Exogyra ponderosa* and *Placenticeras* sp. A 4-inch bed of dark-gray chalk at top	11
1.	Sandstone, yellowish brown, massive, forming a ledge, with lignite seam near base, and *Placenticeras* sp., *Exogyra ponderosa*, and shark teeth	22
	Total	1,171

Unconformity.
Pen Formation.

Chisos Pen.—Three sections of beds near Chisos Pen (Pl. II; N–O, 13) now included in the Aguja Formation are given by Udden (1907a, pp. 46–47); from these the writers have compiled a composite section (Pl. VII, no. 16). Most of the strata are marine. Due to extensive cover, the relations of the Aguja Formation and beds assigned by Udden to the Tornillo (Javelina of this report) are not clear. The exposed beds are mostly sandstone containing a ledge of *Flemingostrea pratti* and the thick clay above the basal sandstone of other areas is absent. Also *Exogyra ponderosa* and *Placenticeras* sp. were not found. This suggests that the lower Aguja is absent and that the basal beds exposed at Chisos Pen are equivalent to some part of the upper marine section at other localities.

Tule Mountain area.—Farther west, 905 feet of the Aguja Formation, including a thick marine clay, occur in the Maverick Mountain anticline north of Tule Mountain (Pl. II; M, 10). Here the basal sandstone is not more than 3 feet thick and is overlain by 520 feet of marine clay containing several thin lenticular sandstone beds, coal beds, and bituminous clay. The clay is followed by a sandstone 15 feet thick, which is overlain by alternating sandstones and clay. *Flemingostrea pratti* occurs in conspicuous reefs at several levels. Description of the lithology and associated fossils follows.

Section of Aguja (measured by planetable) adjacent to the Park road north of Tule Mountain (Pl. VII, no. 15).

		Thickness (Feet)
	Javelina Formation.	
	Gradational contact.	
	Aguja Formation—	
	Nonmarine beds	
49.	Sandstone, white, platy	14
48.	Clay, yellowish, containing lenses of sandstone and coal	8
47.	Sandstone, yellowish gray, interbedded with clay	13
46.	Coal bed	1
45.	Sandstone, yellowish gray, and clay	3
44.	Coal bed	2
43.	Clay, yellowish, sandy	15
	Approximate top of marine beds	
42.	Sandstone, brown, cross-bedded, with *Flemingostrea pratti*, *Inoceramus cummingsi*, and other pelecypods	36
41.	Covered interval	
40.	Sandstone, brownish	10
39.	Clay, yellowish gray	8
38.	Sandstone, brown	10
37.	Clay, yellowish gray	20
36.	Sandstone, gray	15
35.	Clay, yellowish gray, with thin platy sandstone	82
34.	Sandstone, brown, with *Flemingostrea pratti*, *Inoceramus cummingsi*, and gastropods	9
33.	Clay, yellow, silty, with concretions	3
32.	Coal bed	2
31.	Clay, yellow, silty	14
30.	Coal bed	2
29.	Clay, yellowish, silty	12
28.	Sandstone, reddish brown, platy. Beds about 1 foot thick at base and top are a *Flemingostrea pratti* reef. The top reef also contains *Inoceramus cummingsi*	33
27.	Clay, gray	23
26.	Sandstone, brown	16
25.	Clay, gray, with thin lenses of brown sandstone	38
24.	Sandstone, reddish brown, platy	2

		Thickness (Feet)
23.	Clay and sandy clay, yellowish gray	22
22.	Clay, gray, marly, with calcareous concretions, 1 × 2 × 3 feet in size	5
21.	Clay and sandy clay, yellowish gray	36
20.	Sandstone, yellowish	2
19.	Clay and sandy clay, yellowish	17
18.	Sandstone, brown	1
17.	Clay, yellowish gray, with concretionary zone 9 feet above base	21
16.	Sandstone, brown	1
15.	Clay, yellowish gray	29
14.	Coal bed in carbonaceous clay	7
13.	Clay, silt, and silty sandstone, yellowish gray	71
12.	Sandstone, yellowish, platy	2
11.	Clay, yellowish, with bituminous layers	16
10.	Sandstone, brown, platy	2
9.	Clay, dark, lignitic, with coal bed 2 feet thick at base	14
8.	Clay, yellowish	46
7.	Sandstone, yellowish brown, platy	2
6.	Clay, yellowish gray, with a few thin layers of platy sandstone	78
5.	Sandstone, brown, silty, with reef of *Flemingostrea pratti*	4
4.	Clay, yellowish	29
3.	Clay, yellow, with concretions and *Eutrephoceras* sp.	4
2.	Clay, yellow, silty clay, and thin platy sandstone	68
1.	Sandstone, yellow and gray, platy	3
	Total	871

Unconformity.
Pen Formation.

Dawson Creek.—At Dawson Creek (Pl. II; M, 9) the Aguja Formation is probably about as thick as in the preceding section, but the upper part is mostly concealed (Pl. VII, no. 14). The top of the marine beds may be in the covered interval at a position considerably higher than indicated on Plate VII. The rocks in the basal part of the section differ much in lithology and thickness from those north of Tule Mountain, only 2½ miles away (Pl. VII, nos. 14 and 15), emphasizing the difficulty of correlating beds within the Aguja. At Dawson Creek the basal Aguja sandstone is 30 feet thick as compared with 3 feet north of Tule Mountain. The lower marine clay is about 175 feet thick as compared with 520 feet in the Tule Mountain section. Like most of the Aguja Formation, the sequence contains coal interbedded with layers containing marine fossils. Lithologic description and thickness of exposed beds, obtained by planetable, are shown on section 14 of Plate VII.

Tortuga Mountain.—At Tortuga Mountain (Pl. II; H–J, 17) the Aguja Formation is domed around the central intrusion. The base is not exposed but the sequence resembles that at Chisos Pen. In a sandstone bed on the north flank of the dome, molds and casts of pelecypods are abundant, but the upper Aguja (nonmarine) and Javelina beds are truncated by Tertiary age strata. Similar relations occur at the north end of the Cow Heaven anticline (Pl. II; G, 16–17).

The Aguja Formation, containing marine fossils, crops out in the Basin (Pl. II; L, 16). The formation is mostly covered and neither the upper nonmarine Aguja nor Javelina occurs. At Lone Mountain (Pl. II; O, 19), an outlier northeast of the Chisos Mountains, the upper Aguja Formation containing dinosaur teeth and bone fragments crops out in a saddle near the top of the peak. The peak is surrounded by alluvium and the top of the Aguja was not seen. Probably the Chisos Formation (Upper Eocene) truncates the Aguja southwest of Lone Mountain and also in the Basin.

COAL RESOURCES

The most conspicuous coal beds are in a belt extending from the southern flank of the Rosillos Mountains southwestward to the mouth of Terlingua Creek, and also along Terlingua Creek northward to the latitude of Hen Egg Mountain and the Adobe Walls anticline (Pl. I). The coal beds are mostly less than 2 feet thick and are commonly associated with carbonaceous clay up to 20 feet thick. Where the coal beds are adjacent to intrusions, they are anthracite, but where they are not close to intrusions, the deposits are low-grade, high-ash subbituminous coal or lignite. The B.t.u. values range from 8,432 to 11,598. The coals within the Park were not marketed commercially but hand-picked ma-

terial was used to a limited extent by some of the nearby ranchers in their forges for shaping horseshoes and other blacksmith requirements and to a very limited use for heating. Analyses of the coal from four localities are shown in table 5.

TABLE 5. *Analyses of coal samples, Udden (1907a, pp. 95–97) and Baker (1935, p. 322).*

	1	2	3	4
Moisture	2.44	4.68	6.12	12.61
Ash	3.43	16.60	14.42	57.53
Sulfur	0.93	0.88	1.32	0.90
Volatile combustible material	15.38	24.20	34.72	17.90
Fixed carbon	77.95	54.52	44.74	11.96
Totals	100.13	100.88	101.32	100.90

1. Near the Park boundary south of the Rosillos Mountains (Pl. II; S, 20).

2. Rough Run Creek, south of Slickrock Mountain (Pl. II; O, 13).

3. Cottonwood Creek near Chisos Pen (Pl. II; O, 13).

4. Near the mouth of Terlingua Creek (Pl. II; H, 6).

The largest deposit of coal known in the region occurs about 6 miles north of Study Butte (section 242, block G–4, H. E. & W. T. Ry. Co. survey, Brewster County). Coal from this deposit was mined for several years and used to make producer gas for power and fuel at the Terlingua quicksilver mining operation. An analysis is not available, but the components are probably within the range of values listed in the above analyses.

Carbonaceous shale or clay, commonly associated with lignite, is widespread throughout the Aguja. The deposits range from brown to chocolate-colored or black carbonaceous clay to weathered, impure lignite with films or crusts of gypsum, yellow streaks of jarosite, and grains of reddish-amber resin. Deposits of this type have been mined locally for several years in the Terlingua area (outside the Park) and sold as a soil conditioner. Analyses of two samples from near the above "coal mine" show the following composition:

	Percent	*Percent*
Moisture	12.61	10.94
Ash	57.53	41.35
Volatile combustible material	17.90	28.47
Fixed carbon	11.96	18.97
Totals	100.00	99.73

FOSSILS AND AGE

The following have been identified from the Aguja Formation:

Exogyra ponderosa Roemer, 1852
Inoceramus cummingsi Cragin, 1893
Flemingostrea pratti Stephenson, 1923
Ostrea pratti Stephenson, 1923
Eutrephoceras dekayi (Morton, 1833)
Cardium sp.
Placenticeras sp.
Tylostoma sp.
Phobosuchus riograndensis Colbert & Bird, 1954

Exogyra ponderosa is the most common fossil in the Aguja Formation. It was found in the basal sandstone at most localities and ranges upward through the marine clay and into the uppermost marine sandstone and shale. *Placenticeras* sp. was found in most basal sandstone exposures and ranges upward for an unknown distance into the marine clay. *Inoceramus cummingsi* is abundant in some sandstone layers at Dawson Creek and Tortuga Mountain and is present but not abundant in beds north of Tule Mountain and the basal beds at Chisos Pen. *Flemingostrea pratti* occurs in a ledge at one level near Chisos Pen, two ledges at Dawson Creek, and several levels north of Tule Mountain. The lower Aguja correlates with the Upson in the Rio Grande embayment and the lower Taylor in central Texas.

Incomplete dinosaur skeletons, single dinosaur bones and bone fragments, turtle remains, garfish scales, and shark and ray teeth are locally abundant in the upper Aguja (fig. 52). In 1938, prior to establishment of the Park, an expedition led by Barnum Brown from the American Museum of Natural History, New York, made extensive collections from the area. Study of this material is not complete, but the specimens include a giant crocodile, *Pho-*



Fig. 52. Dinosaur bone, about 3½ feet long, in upper Aguja Formation about 1 mile northwest of Dripping Springs (Pl. II; Q, 15).

bosuchus riograndensis (fig. 53), and ceratopsian (like the familiar *Triceratops*) and hadrosaurian forms (like the amphibious duck-bill) were collected. Several of the specimens came from the Glenn Springs locality (Pl. II; G, 19). E. H. Colbert, Dr. Brown's successor, re-visited some of the localities during May 1951 and again in 1956 and identified (personal communication) incomplete lower and upper jaws, with teeth, of a *Phobosuchus riograndensis* from Aguja beds about 1 mile northwest of the lower Tornillo Creek bridge (Pl. II; J, 24). This jaw is now at The University of Texas; accession numbers are: upper jaw, B.E.G. 40571–1; lower jaw, B.E.G. 40571–2. Additional dinosaur material was collected by a party from Texas Western College under the supervision of W. S. Strain, and a ceratopsian skull collected at this time is on exhibit in the Museum at Texas Western College in El Paso. W. N. McAnulty made a collection for the University of Oklahoma. Dinosaur localities are indicated on the geologic map (Pl. II). This fauna indicates that the Aguja correlates with the Judith River of Montana and the Belly River of Alberta.

Fossil wood is also abundant in the upper Aguja beds. Most of it is silicified and there is some agate. It includes sections of tree trunks up to 3 to 5 feet in diameter; some are 30 to 40 feet long. Commonly, the logs are in groups and associated with individual sandstone beds, suggesting stream transportation and concentration of a "log jam" in shallow water. Several agatized stumps, with roots firmly embedded in the rock, occur near the west bank of Tornillo Creek (Pl. II; P, 22) west of the McKinney Hills (fig. 54). Detailed studies and identification have not been attempted. Most of the specimens show the structure of gymnosperma, but angiosperma, palm wood, and palm fronds also occur.

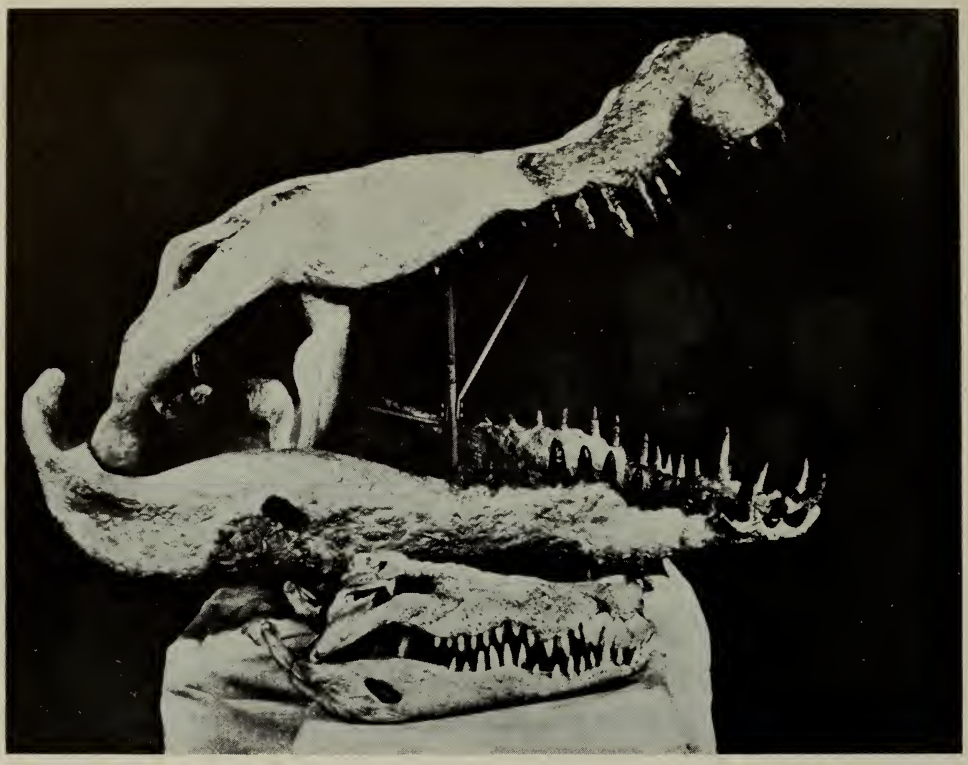


FIG. 53. Skulls of *Phobosuchus riograndensis* on exhibit at the American Museum of Natural History, New York. Collected from Aguja beds near Glenn Springs (Pl. II; G, 19). (Photograph by American Museum of Natural History.)

TORNILLO (New) GROUP

The Tornillo Clay was named by Udden (1907a, pp. 54–60) for rocks that "are well exposed for many miles along Tornillo Creek," but he did not give a detailed description of the formation in the type area. Udden believed that the formation was Late Cretaceous in age, and it is true that Cretaceous plants and vertebrates occur in the lower part. However, Wilson et al. (1952, p. 7) found that the upper part of the Tornillo Clay in Tornillo Creek valley and elsewhere contains Tertiary mammals, so that the original formation bridges the Cretaceous-Tertiary boundary. The Tornillo Clay is redefined here as the Tornillo Group, divided into the following new units: the Javelina Formation of Late Cretaceous age and the Black Peaks (Paleocene) and Hannold Hill (Lower Eocene) Formations of early Tertiary age.

Javelina (New) Formation

GENERAL FEATURES

The name Javelina Formation is here proposed for the Cretaceous part of the original Tornillo Clay. The name is from Javelina Creek in the northeastern part of Tornillo Flat. The Javelina is nominally a clay unit containing some lenticular masses of yellowish-gray, yellowish-brown, and dark-brown, cross-bedded sandstone (fig. 55). The clay is mostly bentonitic and is varicolored in shades of dull gray, olive green, maroon, and dirty brown (fig. 56). It is fine textured and mostly appears structureless except for the color bands. It contains impure concretionarylike nodules of calcium carbonate ¼ inch to 2½ inches across with a few up to 8 inches across. They have rough surfaces and some no-



FIG. 54. Agatized tree stump, with roots embedded in the rock. West side of Tornillo Creek (Pl. II; P, 22).



FIG. 55. Lenticular, cross-bedded sandstone and clay in the Javelina Formation south of Dawson Creek, northwestern part of the Park. (Photograph by National Park Service).



Fig. 56. Varicolored clay and thin sandstone beds in the Javelina Formation. (Photograph by the National Park Service.)



Fig. 57. Rounded knob of Javelina clay south of Dawson Creek. The black rock in the upper left skyline is Tertiary lava. (Photograph by National Park Service.)

dules have radiating interior structures or shrinkage cracks, commonly filled with calcite. The clay is impervious and weathers characteristically into rounded topographic forms (fig. 57). Udden (1907a, pp. 57–58) has given a classic description of weathering and creep in these rocks:

> The Tornillo Clays weather in a most singular fashion. It has already been noted that they are so fine in texture as to be quite impervious to water. Inversely they will not yield enough moisture to enable plants to grow, except where their surface has been mixed with or covered by some land drift. When rain falls the surface of the bare clay swells up into an exceedingly sticky mud, which renders the land practically impassable to man and beast. Pools of water will stand on the ground after heavy showers and they will evaporate away by heat and sunshine while only a small part of the moisture filters into the clay. When the ground dries, the clay shrinks and cracks extensively, but as the moisture only affects the upper one or two feet, the cracks are limited to the same depth. The clay retains the moisture with such tenacity that the outer layers of a moist lump will warp and break off while the kernel is yet somewhat plastic. As a result, the drying clay breaks up into irregular angular hard lumps, less than an inch in diameter. These cover the unweathered strata beneath to depths of from one to three feet on hills and slopes where the clay is bare. They are hard and tough, sometimes wholly separate from each other, and sometimes partly adhering. With every rain the process is repeated, the lumps swell up and are again dried and warped. The swelling as well as the warping produces a small creeping motion among the clay lumps, small in extent but evidently powerful. On slopes gravity aids all movements in a downward direction and counteracts all other movements. In the long run the accumulated effect of this influence results in a motion in the direction of the slope. The whole bed of clay lumps thus creeps forward like a glacier. The movement is evidently very slow, but many of the clay hills show unmistakable indication of its reality in rounded flowing contours.

The sandstone bodies are commonly lenticular and are varied in both lateral and vertical dimensions (fig. 58). Most of them are cross-bedded or ripple marked, some are conglomeratic (fig. 59), and many are probably channel deposits. Dinosaur bone and fossil wood fragments are common in



Fig. 58. Lenticular sandstone of Javelina Formation along Dawson Creek south of Study Butte. (Photograph by National Park Service.)



FIG. 59. Conglomeratic channel sandstone in clay of Javelina Formation along Dawson Creek. (Photograph by National Park Service.)

them. Whole bones and large sections of fossil trees are more commonly found in sandy clay beds; in places these are crowded together suggesting they were not transported far and were deposited in shallow water or on a mud flat.

The Javelina Formation has all the characteristics of a continental deposit. Lack of sorting and lack of structure in the clay suggest deposition from suspension in lakes whose currents were intermittent and local. Periodic oscillations drained or shifted the water bodies and caused channeling. A few widespread sandstone layers are probably flood-plain accumulations; they show repeated scour and fill, probably produced by streams and wind. In places the sandstones are channeled, the channels filled, and the sandstones covered by massive clay (fig. 60).

LOCAL FEATURES

Tornillo Creek valley.—In the Black Peaks area, northwest of the McKinney Hills (Pl. II; Q, 22), the Javelina Formation is 244 feet thick with both base and top preserved (Pl. VII, no. 18). Here it is mostly bentonitic clay that is overlain by a bedded conglomeratic sandstone, 22 feet thick, whose irregular unconformable base is the Mesozoic-Cenozoic boundary. Middle Paleocene mammal remains near Loc. T2 (Pl. II) occur 180 feet above the contact and a dinosaur bone occurs 33 feet below. This is the thinnest measured section of Javelina in the Park where both upper and lower contacts are preserved and it lies in an area where much of the Javelina was eroded prior to the Tertiary. Southward, this thin Javelina extends for several miles in a narrow band along the western rim of the McKinney Hills to where it is covered by gravel. Description of the section follows.

Section of Javelina Formation (measured by planetable) near Black Peaks (Pl. II; Q, 22) *northwest of the McKinney Hills* (Pl. VII, no. 18).



FIG. 60. Clay-filled channel in sandstone, Javelina Formation, along Dawson Creek. (Photograph by National Park Service.)

	Thickness (Feet)
Black Peaks Formation (Paleocene).	
Unconformity.	
Javelina Formation—	
6. Clay, maroon and greenish, bentonitic, with calcareous nodules and 2-foot beds of gray sandstone at base	25
5. Clay, greenish gray, bentonitic	8
4. Sandstone, yellowish gray and brownish, with dinosaur bone	4
3. Clay, maroon, gray, and greenish gray mottled, with thin, poorly indurated sandstone beds, mostly covered	182
2. Sandstone, yellowish gray and brownish, with dinosaur bone fragments	9
1. Clay, gray and maroon mottled, bentonitic, with calcareous nodules	16
Total	244
Gradational contact.	
Aguja Formation.	

On the northeast side of Tornillo Flat (Pl. II; R–S, 20–21), north and northwest of Black Peaks, the basal Javelina grades downward into Aguja; the top is in fault contact with the younger Hannold Hill Formation (Lower Eocene). The Javelina is varicolored, nodular, bentonitic clay with a few thin lenses of brownish sandstone and contains dinosaur bones and fragments of wood. Here the formation is about 300 feet thick.

The Javelina Formation crops out in upper Tornillo Creek valley from near Grapevine Hills at the east, westward to near Smallpox Well (Pl. II; Q–S, 14–19). Near Grapevine Hills, strata have been arched by the Grapevine intrusion. The Javelina rests on Aguja on the north and northwest sides of the dome and is overlain on the east side by Tertiary rocks from which Lower Eocene mammal remains were collected (Pl. II; Loc. T7). Farther northwest about 300 to 400 feet of Javelina beds are exposed along the axis of a syncline. The Javelina rests on Aguja but the top is not exposed.

North of the Chisos Mountains.—North of Pulliam Peak (Pl. II; M–O, 15), the Javelina Formation is 340 feet of mottled gray and maroon bentonitic clay with a few

argillaceous sandstone beds. It is mostly covered, but several fragments of dinosaur bones and logs are exposed. The formation overlies a sandstone bed of the Aguja Formation 45 feet thick and is overlain by a sandstone about 40 feet thick, irregular at base, containing Tertiary mammal remains (Lower Eocene?) (Pl. VII, no. 17).

Tule-Dogie Mountains area.—The Javelina Formation crops out in the flank of the Maverick Mountain anticline, along Rough Run Creek, and in the badlands between Dogie and Christmas Mountains (Pl. II; N–P, 11–12). It is mottled and banded gray, yellowish-gray, and maroon bentonitic clay with small calcareous nodules and a few thin beds of gray or brown platy sandstone. It overlies the Aguja Formation and is overlain by the Alamo Creek Basalt, the oldest Tertiary (Upper Eocene?) lava in the western part of the Park. Dinosaur bone and fossil wood fragments occur at several levels. Detailed descriptions of the lithology and fossils in a section 534 feet thick follow (Pl. VII, no. 15).

Type section of Javelina Formation (measured by planetable) exposed between the Park road and Tule Mountain (Pl. VII, no. 15).

		Thickness (Feet)
Upper Eocene.		
	Tuff with scattered unidentifiable mammal bone fragments in Chisos Formation.	
	Alamo Creek Basalt.	
Unconformity.		
Javelina Formation—		
19.	Clay, gray and maroon, bentonitic	20
18.	Covered	48
17.	Clay, gray, gray white, and maroon, bentonitic, with a 1-foot bed of yellowish sandstone, 28 feet above base	54
16.	Covered	97
15.	Sandstone, yellowish gray, massive, with clay-ball conglomerate	6
14.	Clay, maroon, gray, and gray white, bentonitic, with calcareous nodules, partly covered	38
13.	Clay, gray and maroon, bentonitic, mostly covered	54
12.	Sandstone, yellowish gray	7
11.	Clay, yellowish, silty, with tree trunk 4 feet in diameter	17
10.	Mudstone, gray white, concretionary	4
9.	Mudstone, gray, gray white, and silty clay	44
8.	Mudstone, gray, with dinosaur bones and fragments of tree trunks, 12 inches across, about 5 feet above base	11
7.	Sandstone, gray, platy	2
6.	Clay and mudstone, gray	25
5.	Sandstone, gray, platy	3
4.	Clay and mudstone, gray	14
3.	Mudstone, gray, sandy	4
2.	Covered	78
1.	Clay, pinkish gray	8
	Total	534
Gradational contact.		
Aguja Formation.		

Dawson Creek.—The Javelina Formation exposure south of Dawson Creek is the thickest section in the Park and is exceptionally well exposed except for the basal 35 feet. The formation is 936 feet thick and consists of varicolored, nodular, bentonitic clay, sandy clay, and thin irregular lenticular sandstone, with dinosaur bones, wood, and a few thin coal and lignite beds. Although the base is covered, nearby exposures indicate that there is no marked lithologic difference between the basal Javelina and the upper Aguja. Here the Javelina is unconformably overlain by the Alamo Creek Basalt (Upper Eocene). Details of a section follow (Pl. VII, no. 14).

Section of Javelina Formation (measured by planetable) at the type locality south of Dawson Creek (Pl. VII, no. 14).

		Thickness (Feet)
Upper Eocene and Oligocene.		
	Chisos Beds, tuffaceous.	
	Alamo Creek Basalt.	
Unconformity.		
Javelina Formation—		
41.	Clay, yellowish gray, bentonitic	23
40.	Clay, brownish purple, bentonitic	17
39.	Clay, buff, bentonitic	6
38.	Clay, reddish chocolate brown, bentonitic, slightly mottled with gray and yellow, weathers pinkish gray, with four gray 1-foot sandstone ledges. Concretions as much as an inch across near base	92
37.	Sandstone, gray	8
36.	Clay, gray, bentonitic	10
35.	Coal bed	1
34.	Clay, chocolate, bentonitic	11
33.	Sandstone, gray, platy, in beds as	

		Thickness (Feet)
	much as 4 feet thick, with interbedded lenses of gray clay	9
32.	Clay, gray and buff, bentonitic	6
31.	Sandstone, gray, platy	5
30.	Clay, gray, sandy, with a 1-inch platy sandstone bed	11
29.	Clay, gray, buff, chocolate, with thin beds of platy sandstone	42
28.	Coal bed	3
27.	Clay, gray, bentonitic	7
26.	Sandstone, yellowish buff, fine grained, quartzose, poorly cemented, with conglomerate of wood fragments at base	30
25.	Clay, brownish gray and reddish brown, bentonitic, in 4- to 8-foot beds or lenses, with two or more beds of light-gray, soft, fine-grained sandstone. Parts contain calcareous concretions as much as an inch across	118
24.	Clay and sandy clay, purple and buff, bentonitic, with ½- to 1-foot yellowish-gray sandstone beds	68
23.	Clay, purple, bentonitic	12
22.	Clay and sandy clay, buff, bentonitic, with thin sandstone lentils, a dinosaur bone, and wood fragments	44
21.	Sandstone, gray, cross-bedded, lenticular, with dinosaur bones	5
20.	Clay, gray and maroon, bentonitic, weathering purple, with calcareous concretions ½ inch to 2 inches across	88
19.	Sandstone, gray, platy	6
18.	Clay, gray, bentonitic, weathering purple, with dinosaur leg bone 13 feet below top	75
17.	Sandstone, gray, cross-bedded, with dinosaur bone and wood fragments	7
16.	Clay, gray, bentonitic	29
15.	Sandstone, gray	4
14.	Sandy clay, gray	18
13.	Sandstone, gray, with dinosaur bone fragments	4
12.	Clay, gray, bentonitic, weathering purple	4
11.	Sandstone, gray, fine, argillaceous, that weathers with peculiar, nearly vertical, yellow to brown streaks 1 inch to 3 feet wide	10
10.	Clay, light purple, with concretions 6 to 8 inches across	19
9.	Sandstone, gray, coarse grained, cross-bedded; 5 feet above base is a 1-foot conglomerate bed containing clay-ball pebbles and dinosaur bone fragments	12
8.	Clay, gray and maroon, bentonitic	55
7.	Sandstone, buff, fine, poorly cemented, argillaceous, alternating with beds of pinkish, bentonitic clay	18
6.	Clay, gray and buff, bentonitic	4
5.	Clay, gray, sandy	4
4.	Clay, alternating bands of gray and purple, bentonitic	7
3.	Sandstone and sandy clay, buff, fine	4
2.	Clay, gray, bentonitic, exposed near bed of Dawson Creek	5
1.	Covered (along Dawson Creek; includes the Aguja-Javelina contact)	35(?)
	Total	936

Gradational contact(?) covered.
Aguja Formation.

The Javelina Formation forms an irregular band of outcrop from near Dawson Creek, southward to Castolon (Pl. II; G–M, 9), but is extensively covered by pediment gravel from the mountains. Where the base is exposed it is gradational with the Aguja Formation; the top is unconformable with the Alamo Creek Basalt. In this area the thickness varies from 936 feet near Dawson Creek to 200 to 300 feet east of Peña Mountain (Pl. II; J, 9) and less than 50 feet west of Sierra Aguja (Pl. II; K, 5).

In the broad plain south of Punta de la Sierra, bounded by the Cow Heaven anticline on the east and by the southeast end of Cerro de Chino (Pl. II; B–F, 14–17) on the west, the Javelina has been exposed by arroyos that cut through the gravel. The clay beds are exposed in places and because of the poor exposures the thickness cannot be determined accurately, but it probably is comparable to that near Dawson Creek (936 feet).

The Javelina Formation is exposed around Chilicotal Mountain and in the valley northeast of Talley Mountain (Pl. II; F–K, 20–22), where it is highly varicolored bentonitic clay with thin sandstone layers that contain wood. In this area the Javelina Formation is much deformed, but it is probably about 50 feet thick northeast of Glenn Springs and more than 300 feet thick northeast of Talley Mountain and east of Chilicotal Mountain.

FOSSILS AND AGE

The Javelina Formation in Big Bend National Park may be a nonmarine equivalent of part of the Navarro Group rocks in southwest, central, and northeast Texas, but a definite correlation is not possible. The Javelina is more nearly comparable to the nonmarine Escondido Formation of Navarro age in the Rio Grande embayment (Maverick County) (table 2, p. 30). *Alamosaurus* sp. bones were collected by Brown (1940) from the Javelina and support a Maestrichtian age. *Alamosaurus* has also been found in the Hell Creek Formation of Late Cretaceous age in Petroleum County, Montana. The fossil wood of the formation has not been studied in detail. Woody structures preserved during petrifaction suggest that both angiosperma and gymnosperma occur; they appear to be the same types of trees as those found in the Aguja Formation.

RELATION BETWEEN GULFIAN AND TERTIARY

Lithology of the Gulfian deposits suggests that tectonic movements began as early as the time of deposition of the San Vicente Formation and increased in intensity and magnitude to the end of the epoch. During deposiiton of the Aguja, the area emerged from the shallow sea, and tectonic activity continued during deposition of the nonmarine Aguja and Javelina Formations, culminating with strong deformation near the close of Mesozoic time. These tectonic disturbances were accompanied by intrusive igneous activity, forming the sills in the Boquillas, the sills that are concordantly folded in the Aguja on Mariscal Mountain and Cow Heaven anticline, and the bentonitic clay in the Javelina.

Uplift caused extensive erosion which in places removed all of the Javelina and part of the Aguja from the Chisos Mountains area. The pre-Tertiary surface was progressively overlapped by the Tertiary rocks from southeast to northwest across the Park. Near Tornillo Creek, northwest of the McKinney Hills (Pl. II; Q, 22), Paleocene beds overlie 244 feet of Javelina (Pl. VII, no. 18). Southwest of Glenn Springs (Pl. II; H, 19) Paleocene beds overlie Javelina which is not more than 50 feet thick. Lower Eocene beds overlie 300 to 400 feet of Javelina east of Grapevine Hills and they rest on 340 feet of Javelina north of Pulliam Peak (Pl. VII, no. 17). Beds probably of Lower Eocene age rest on marine Aguja in the Basin, at Tortuga Mountain, and probably east of Lone Mountain. Paleocene and Lower Eocene strata evidently do not extend west of the Chisos Mountains, for in that area Upper and Middle Eocene rocks are in contact with the Cretaceous formations. In most places in the Park, they rest on the Javelina that ranges in thickness from 936 feet along Dawson Creek in the northwest part of the Park to about 50 feet at Sierra Aguja, but at the north end of the Cow Heaven anticline they rest on marine Aguja. Farther northwest, outside the Park, the Upper Eocene strata overlap Aguja, Pen, and Boquillas Formations on the flanks of the Terlingua monocline and the Solitario.

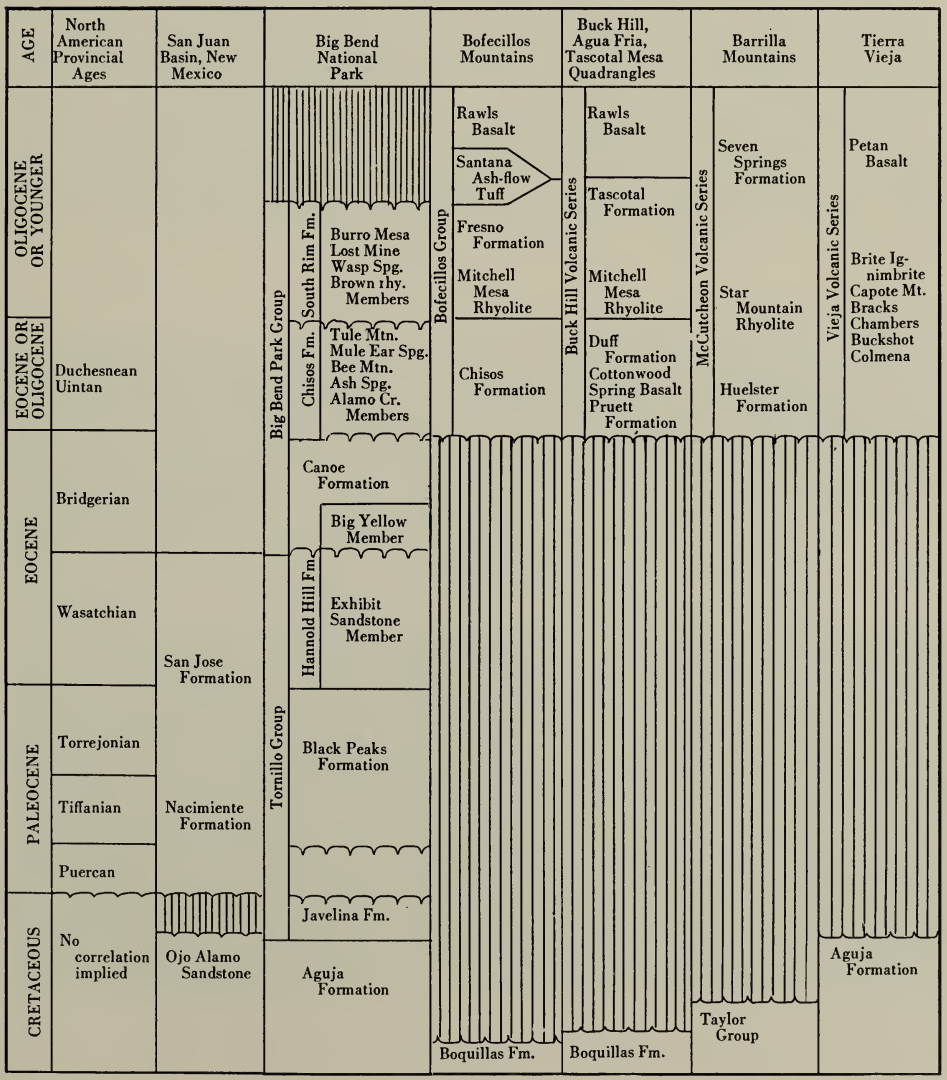
Tertiary System

Tertiary rocks, including sandstone, conglomerate, shale, pyroclastics, tuffs, and lava, are preserved in Big Bend National Park and in a much larger area to the west and northwest. In the Park this sequence is broadly divisible into a lower nonvolcanic unit and an upper volcanic unit. The lower nonvolcanic unit, the middle and upper part of the Tornillo Group, is mostly sandstone, conglomeratic channel sandstone, and clay of Paleocene and Lower Eocene ages. The upper volcanic unit, or Big Bend Park Group, consists of (1) the Canoe Formation of sandstone, conglom-

eratic sandstone with igneous pebbles, tuffaceous clay and mudstone, vitric tuff, and some lavas of Middle Eocene age; (2) the Chisos Formation of coarse, massive conglomerate, tuffaceous sandstone, tuff, and several lava beds, not all precisely dated but mostly Upper Eocene age; and (3) the South Rim Formation, largely of lava and flow breccia, probably of Oligocene age (table 6).

Most outcrops of Tertiary rocks are discontinuous, and correlation would be difficult without the aid of vertebrate fossils. Most of the vertebrates have been discovered during the past 15 years, and some of them have permitted the accurate dating of certain units of the Tertiary sequence. Petrography and chemical analysis have been helpful in correlating many of the lavas, and the potassium-argon method of analysis has been used to date some of them.

TABLE 6.—Regional correlation of Tertiary formations.



Black Peaks (New) Formation

GENERAL FEATURES

The oldest Tertiary rocks in west Texas are the Black Peaks Formation, named from three small black peaks (fig. 61) on Tornillo Flat, northwest of the McKinney Hills (Pl. II; Q, 22). The Black Peaks Formation is approximately the middle part of Udden's (1907a, pp. 54–60) Tornillo Clay, and the rocks contain Paleocene fossils. The formation is 284 feet thick at the Black Peaks locality but thickens to 866 feet about 5 miles to the northwest.

The Black Peaks Formation is an alternation of sandstone and clay, much like the upper part of the Aguja Formation (fig. 62). Most of the sandstones are gray or gray white and lighter colored than those in the Cretaceous. Some contain cannonball concretions that split into platy layers, unlike the massive concretions in the Aguja (fig. 63). Much of the clay is mottled gray and maroon like much of the Javelina clay, but it lacks the calcareous nodules of the latter. The Black Peaks Formation has more sandstone than either the Javelina below or the Hannold Hill Formation above (Pls. VII and IX).

The base of the Black Peaks is a sandstone unit which is cross-bedded and conglomeratic (fig. 62). At most places it overlies the Javelina with an irregular base and lies between the highest known dinosaurs and the lowest recognized Paleocene mammals. The top of the Black Peaks is at the base of a sandstone below Lower Eocene (Wasatchian) mammalian remains.

LOCAL FEATURES

East-central Tornillo Flat.—At Black Peaks (Pl. II; Q, 22) the lowest bed of the formation is a massive, gray, cross-bedded sandstone with basal conglomerate



Fig. 61. Type locality of the Black Peaks Formation northwest of the McKinney Hills (Pl. II; Q, 22).

A, The three black basaltic peaks from which the formation was named. B, The Javelina—Black Peaks contact. C, Fossil locality T2.



FIG. 62. Basal Black Peaks Sandstone, near the type locality, on Tornillo Flat, northwest of the McKinney Hills.



FIG. 63. Cannonball concretions from the Black Peaks Formation on northern Tornillo Flat (Pl. II; R, 20).

as much as 35 feet thick (fig. 62). It rests on clay of the Javelina, one of whose interbedded sandstones contains dinosaur bones. The higher part of the Black Peaks sequence at this locality is alternating clay and sandstone. At two levels, 117 feet and 135 feet above the base, pebbly sandstone beds in clay yield mammals (Loc. T2), including teeth, partial jaws, and miscellaneous bones. A fresh-water limestone 185 feet above the base contains pelecypods and gastropods. The top of the formation is covered by Recent silts and the relation to the overlying Hannold Hill Formation is not clear. A section measured at this locality (Pl. IX, no. 35) follows.

Section of Black Peaks beds (measured by planetable) at Black Peaks, northwest of McKinney Hills (Pl. IX, no. 35).

	Thickness (Feet)
Covered.	
Black Peaks Formation—	
18. Sandstone, yellowish gray, coarse grained, conglomeratic	15
17. Clay, gray, maroon, and mottled	40
16. Sandstone, yellowish gray to brown, coarse grained	5
15. Clay, gray and mottled, partly covered	20
14. Sandstone, gray	15
13. Limestone, fresh-water, containing *Viviparus raynoldsanus* and *Ellipto mendax*	5
12. Clay, gray, maroon, and mottled, partly covered	43
11. Clay, yellowish and pinkish gray, pebbly, silty, containing Ptilodontidae cf. *Mimetodon douglassi, Psittacotherium* cf. *P. multifragum, Periptychus carinidens, ?Tetraclaenodon puercensis*, and crocodile and turtle remains (Loc. T2)	8
10. Clay, gray	8
9. Sandstone and clay, gray, pebbly, with *Ptilodus* sp., *Psittacotherium* cf. *P. multifragum, Periptychus carinidens, ?Tetraclaenodon puercensis*, crocodile and turtle remains (Loc. T2)	8
8. Clay, gray and mottled	6
7. Sandstone, gray white	9
6. Clay, gray, silt, and silty sandstone	32
5. Sandstone, gray, cross-bedded, with conglomerate at base	10
4. Clay, gray	11
3. Sandstone, gray	4
2. Clay, gray	10
1. Sandstone, gray, massive, cross-bedded, conglomerate at base; ranges from 15 to 35 feet thick along the outcrop	35
Total	284
Unconformity.	
Javelina Formation.	

About a quarter of a mile northeast of the above section, 315 feet of nonfossiliferous Black Peaks beds were measured. Lithologic description and thickness of the units are plotted in section 34, Plate IX. A comparison of sections 34 and 35 (Pl. IX) illustrates the rapid change in lithology of the Black Peaks Formation. The rocks are above the basal Black Peaks sandstone beds which are traceable to the Black Peaks locality. The absence of fossils and the general similarity of the rocks to those in the Javelina emphasize the necessity of fossils in order to determine if the rocks of the Tornillo Group are Upper Cretaceous or Tertiary.

North-central Tornillo Flat.—The maximum thickness (866 feet) of the Black Peaks Formation is in the north-central part of Tornillo Flat (Pl. II; R–S, 20). Here the basal strata are platy to fairly massive sandstone containing clay nodules reworked from the underlying Javelina and mammalian bones. The base is irregular and probably the rocks fill a channel. Dinosaur bones occur 40 feet below the contact.

The remainder of the formation here is gray, maroon, and mottled clay alternating with gray, gray-white, and light yellowish-gray sandstone. Beginning 716 feet above the base is a bed of gray-white, medium-grained sandstone, 49 feet thick, with spheroidal weathering, containing mammal and crocodile bones and teeth, turtle remains, and fresh-water gastropods (Loc. T1). The uppermost Black Peaks beds at this locality are 91 feet of gray and maroon clay, mostly covered. These are overlain by the basal sandstone of the Hannold Hill Formation (Lower Eocene). Litho-

logic description of a section measured at this locality follows (Pl. IV, no. 33).

Type section of Black Peaks Formation (measured by planetable) (Pl. II; T, 1), *north-central part of Tornillo Flat* (Pl. IX, no. 33).

		Thickness (Feet)
Hannold Hill (Lower Eocene) Formation.		
Black Peaks (Paleocene) Formation—		
33.	Clay, gray and maroon, partly covered	15
32.	Covered	76
31.	Sandstone, gray white, medium grained, with spheroidal weathering, exposed over several tens of acres, containing *Phenacodus* sp. or *Gidleyina* sp., *Phenacodus* cf. *P. grangeri*, *Psittacotherium* cf. *P. multifragum*, and other mammalian remains, a partial crocodile skeleton, crocodile bones and teeth, turtle remains, and *Viviparus raynoldsanus* (Loc. T1)	49
30.	Clay, gray and maroon, with several fragments of silicified tree trunks as much as 4 feet in diameter	37
29.	Sandstone, gray	34
28.	Clay, gray and maroon	32
27.	Sandstone, gray, with cannonball concretions as much as 1 to 2 feet across that split into platy layers	16
26.	Clay, gray	10
25.	Sandstone, gray and yellowish gray, massive, with turtle bones 6 feet above base	39
24.	Clay, gray and maroon	26
23.	Sandstone, gray	15
22.	Clay, gray and maroon	12
21.	Sandstone, gray, with spheroidal weathering	6
20.	Clay, maroon	4
19.	Sandstone, gray	26
18.	Clay, gray and maroon, with many fragments of silicified wood	35
17.	Sandstone, gray	25
16.	Clay, gray	9
15.	Sandstone, gray and yellowish gray, interbedded with gray clay	18
14.	Sandstone, gray	20
13.	Clay, gray and maroon	20
12.	Clay, varicolored, thin beds of platy, fine-grained sandstone, and siltstone	139
11.	Clay, maroon and gray	34
10.	Sandstone, gray white, cross-bedded, with reddish-brown concretions and seams of ferruginous claystone separated by gray and maroon clay	11
9.	Clay, maroon and gray	7
8.	Sandstone, gray white, cross-bedded, with reddish-brown concretions and seams of ferruginous clay	13
7.	Clay, maroon and gray, partly covered	47
6.	Sandstone, brown, cross-bedded	4
5.	Clay, maroon and gray, partly covered	30
4.	Sandstone, brown, platy	33
3.	Clay, brown and gray	8
2.	Sandstone, grayish white, thin platy to fairly massive, medium to coarse grained in irregular base. Basal few feet conglomeratic with fragments of calcareous nodules reworked from underlying Javelina Formation and fragmental mammalian bones	16
1.	Covered	....
	Total	866
Unconformity.		
Javelina Formation.		

Rock crusher locality.—About a mile northeast of the National Park Service's abandoned rock crusher site on the south side of Tornillo Flat 765 feet of Black Peaks beds were measured (Pl. II; P, 22). The basal bed is a gray-white, cross-bedded sandstone containing unidentifiable mammalian bone fragments, deposited in a channel-like depression in the Javelina. Dinosaur bones occur about 30 feet below the Tertiary-Cretaceous contact (Pl. IX, sec. 26).

Glenn Springs area.—Off the old road, about 2½ miles west-southwest of Glenn Springs, or about 5 miles southeast of Tortuga Mountain (Pl. II; H, 19), is a small area of Black Peaks Formation. The rocks are gray, maroon, and mottled clay and gray-white, cross-bedded sandstone. One of the sandstone beds weathers spheroidally like those on north-central Tornillo Flat (Loc. T1); this bed yielded one partial jaw of ?*Claenodon* sp. cf. *C. procyonoides*, miscellaneous bone scrap, and several specimens of gastropods and pelecypods.

FOSSILS AND AGE

The following fossils were identified from the Black Peaks Formation:

Periptychus cf. *carinidens*
Ptilodontidae cf. *Mimetodon douglassi*
Claenodon cf. *C. procyonoides*
?Tetraclaenodon puercensis
Phenacodus cf. *P. grangeri*
Phenacodus sp. or *Gidleyina* sp.
Viviparus raynoldsanus
Ellipto mendax

The Paleocene age of the Black Peaks Formation is based on the mammalian remains, and this age assignment is supported by the association with fresh-water mollusca of the same species as recognized in the Tertiary of the Great Plains. The rocks in the type locality (Pl. II, Loc. T2), near the three small black peaks on east-central Tornillo Flat (fig. 61), are Torrejonian age; in north-central Tornillo Flat (Pl. II, Loc. T1), the rocks are Tiffanian age. In addition to mammals and fresh-water shells, there are some crocodile bones and teeth, turtle skeletons, garfish scales, fish bones, and much silicified wood. The wood is similar to that found in the Aguja and Javelina Formations. The largest and most spectacular fossil log found in the Park lies in sandstone beds near the base of the formation in central Tornillo Flat (Pl. II; R, 21). Although slightly flattened, the log is more than 10 feet in diameter and is exposed for about 30 feet (fig. 64). Other fragments indicate that several trees were 4 to 6 feet in diameter.

Hannold Hill (New) Formation

GENERAL FEATURES

The Hannold Hill Formation is named from Hannold Hill on the Park road in south-central Tornillo Flat (Pl. II; P, 20–21). The formation is mostly clay and contains less coarse clastic material than the Black Peaks Formation (Pl. IX). Sandstone and channel conglomerates occur, and the vertebrate remains of the formation are from them. Most of the clay is gray and maroon, contains thin layers of sandstone, and is not unlike some of the



Fig. 64. Silicified log exposed near base of Black Peaks Formation in central Tornillo Flat.



FIG. 65. Looking southwestward across the Hannold Hill Formation on Tornillo Flat, Chisos Mountains in background. Immediate foreground is typical of Hannold Hill beds, which are chiefly clay with layers of sandstone, largely covered by alluvial silt.

clay in the Black Peaks and Javelina Formations (fig. 65). Some beds contain calcareous nodules or concretions like those of the Javelina, but the Hannold Hill is the only formation in the Tertiary sequence containing lignite. Although the Black Peaks and Hannold Hill Formations incorporate all the known Tertiary nonvolcanic beds exposed on Tornillo Flat and there are certain lithologic and color characteristics peculiar to each formation, it is doubtful if either can be accurately identified without fossils; however, an attempt was made to show formational boundaries on the geologic map (Pl. II).

The channel sandstones and conglomerates are generally gray, brownish gray, or gray white, coarse grained, and cross-bedded, containing many black chert and Comanchean limestone pebbles. At most places on Tornillo Flat, the basal part of the Hannold Hill Formation is a single channel sandstone unit 20 to 30 feet thick. In places, however, it consists of 100 feet or more of alternating sandstone and clay (Pl. IX). The second unit is predominantly clay with thin layers of sandstone. The clay is gray and maroon, mottled with yellow; commonly, there are small concretions and in some places lignite beds.

Exhibit Sandstone Member.—The next highest prominent unit is the Exhibit Sandstone Member, 320 feet above the base. This member is named from Exhibit Ridge in central Tornillo Flat (fig. 66). It is 12 to 15 feet thick, generally fossiliferous, and forms a cuesta or series of knobs from the bone quarry (Pl. II; R, 21) northward for several miles, and is again exposed in the Canoe Valley (Pl. II; R–S, 20). Southward from the bone quarry, the Exhibit Sandstone is less continuous but was traced with reasonable certainty to near the abandoned rock crusher site in southern Tornillo Flat (Pl. II; P, 21).

The strata between the Exhibit Sand-



FIG. 66. Channel sandstone at Exhibit Ridge in the Hannold Hill Formation. Mammalian remains have been collected from these rocks (Pl. II; R, 21).

stone Member and the overlying Canoe Formation thin northward across the Tornillo Flat from about 500 feet near the abandoned rock crusher site to 27 feet near the Canoe Valley. The thinning is probably due to post-Hannold Hill erosion prior to deposition of the Canoe Formation; angular relations are conspicuous at several places in central Tornillo Flat.

LOCAL FEATURES

Rock crusher locality.—The greatest thickness of Hannold Hill is 833 feet measured about three-fourths of a mile northeast of the abandoned rock crusher site on southern Tornillo Flat (Pl. II; P, 21). The basal unit is a gray-white channel sandstone 10 to 15 feet thick, which is overlain by alternating sandstone and clay. From one of the sandstone units, 70 feet above the base, a tooth of the Lower Eocene mammal *Lambdotherium* and miscellaneous bone scraps were collected. More than 750 feet of varicolored clay and thin sandstone lie between this fossiliferous bed and beds containing the lowest known Middle Eocene fauna. Lithologic description of a section measured at this locality follows (Pl. IX, no. 26).

Type section of Hannold Hill Formation (measured by planetable), about three-fourths of a mile northeast of the abandoned rock crusher site (Pl. IX, no. 26).

		Thickness (Feet)
Canoe Formation.		
Angular unconformity.		
Hannold Hill Formation—		
22.	Clay, maroon and gray	32
21.	Lignite bed	4
20.	Clay, maroon and gray	21
19.	Clay, maroon and gray, mostly covered, but with scattered small exposures	432
18.	Clay, gray and maroon	12
17.	Exhibit Sandstone Member—sandstone, brown and gray, conglomeratic, nonfossiliferous	13
16.	Clay, gray, with calcareous nodules	18
15.	Lignite bed	5

		Thickness (Feet)
14.	Clay, gray	32
13.	Sandstone, gray	9
12.	Clay, red, maroon, and gray, with numerous calcareous nodules	127
11.	Sandstone, reddish, platy, silty	10
10.	Clay, gray	8
9.	Sandstone, brownish, silty	15
8.	Clay, gray	7
7.	Sandstone, brown, cross-bedded, with *Lambdotherium* sp. tooth	34
6.	Clay, gray	4
5.	Sandstone, brown, conglomeratic	15
4.	Clay, gray	15
3.	Sandstone, brown, with unidentifiable mammalian bone fragments	6
2.	Clay, gray	4
1.	Channel sandstone, gray white, cross-bedded, irregular at base, thickness varies from 10 to 24 feet along the outcrop	10
	Total	833

Black Peaks Formation.

Central Tornillo Flat.—The basal part of the Hannold Hill Formation is covered in central Tornillo Flat, and lowest well exposed unit is the Exhibit Sandstone Member (Pl. IX, nos. 30 and 31). In most places it is a gray, irregular, channel-fill conglomeratic sandstone, with clay lenses, that is 1 to 30 feet thick. At one locality in Exhibit Ridge (Loc. T4) this channel sandstone yielded four skulls, two lower jaws, and other skeletal elements of *Coryphodon* sp., a skull and a lower jaw of *Hyracotherium ?vasacciense*, and a lower jaw of *Phenacodus* cf. *P. primaevus* from the same quarry. Some of the fossils were left in place and the National Park Service constructed a glassed-in shelter over them. This exhibit is about 200 yards east of the Park road and about two-tenths of a mile north of Tornillo Creek (Pl. II; R, 21).

At the fossil exhibit the basal bed of the Exhibit Sandstone Member contains the vertebrate remains and is 11 feet thick. Red and gray clay in a 7- to 10-foot lens separates the bone bed from a higher 6- to 9-foot, gray conglomeratic sandstone. The conglomerate pebbles are as much as 3 inches across; the best rounded ones are Comanchean limestone, black chert, and novaculite. Above the Exhibit Sandstone, gray and maroon clay, 115 feet thick, is overlain by the Canoe Formation. A section at the Exhibit locality (Loc. T4) follows (Pl. IX, no. 31).

Partial Hannold Hill section (measured by planetable) near Tornillo Creek bridge (Pl. IX, no. 31).

		Thickness (Feet)
Canoe Formation.		
Angular unconformity.		
Hannold Hill Formation—		
10.	Silty sandstone, gray, thin bedded, interbedded with gray clay containing large calcareous concretions	22
9.	Clay, gray, with concretions up to 12 inches across	20
8.	Sandstone, gray, coarse grained, cross-bedded	8
7.	Clay, gray, with maroon streaks, containing large, flat, calcareous concretions as much as 12 inches across	15
6.	Clay, gray and maroon, mostly covered	40
5.	Clay, gray and maroon	10
4.	Exhibit Sandstone Member—sandstone, gray, cross-bedded, containing well-rounded pebbles of Comanchean limestone and dark and light chert and novaculite as much as 3 inches across	6–9
3.	Clay, red and gray	7–10
2.	Channel sandstone, gray, resting on gray and maroon clay. Mammalian remains include a lower jaw and other parts of *Coryphodon* sp., *Hyracotherium vasacciense* and *Phenacodus* cf. *P. primaevus*	1–11
1.	Clay, gray and maroon	15–26
	Total	144–170

Black Peaks Formation.

About a mile south of the exhibit shelter, near two low mounds on the east side of the Park road, is a small quarry in the Exhibit Sandstone Member (Loc. T5). Here *Coryphodon* sp., *Hyracotherium vasacciense*, and miscellaneous bone scraps were collected. Above the Exhibit Sandstone Member is 115 feet of gray and maroon clay that separates the bone bed from the overlying Canoe Formation (Pl. IX, no. 30). Across the Park road (west) from this locality is the site (Loc. T6) where the first mammalian remains, the lower jaw

of a *Coryphodon* sp., were collected by J. A. Wilson and a group of students in 1951. Similar remains were found east and southeast of Grapevine Hills (Loc. T7).

North side of Tornillo Flat.—The lower half of the Hannold Hill Formation crops out about 2¼ miles west-northwest of the exhibit shelter (Pl. II; R, 20). The thickness of the lower half does not change appreciably northward across Tornillo Flat (Pl. IX, nos. 26 and 33), but the upper half is truncated by the Canoe Formation, and at the Canoe syncline only 27 feet of sandy clay separates the upper Exhibit Sandstone Member from the basal Canoe Formation (Pl. IX, no. 32). The basal Hannold Hill unit is a massive, gray sandstone, with irregular base, that overlies the Black Peaks Formation. It is followed by maroon and gray clay with silty sandstone beds. The Exhibit Sandstone Member is gray, coarse grained, and conglomeratic, is 18 feet thick, and lies only 8 feet below the truncated top of the formation. Lithologic description of beds in a section measured at this locality follows (Pl. IX, no. 33).

Partial section of Hannold Hill Formation (measured by planetable), 2½ miles southwest of the Canoe syncline on northern Tornillo Flat (Pl. IX, no. 33).

		Thickness (Feet)
Top of Hannold Hill Formation eroded.		
Hannold Hill Formation—		
15.	Clay, yellowish	8
14.	Exhibit Sandstone Member—sandstone, gray, coarse grained, conglomeratic at base	18
13.	Clay, gray and maroon	8
12.	Covered	38
11.	Clay, gray and maroon	13
10.	Covered	21
9.	Sandstone, brownish gray, platy	7
8.	Clay, gray, with thin beds of siltstone and sandstone	126
7.	Clay, black	4
6.	Clay, gray	55
5.	Sandstone, gray, with spheroidal weathering	4
4.	Clay, gray	3
3.	Sandstone, gray	3
2.	Clay, gray, with calcareous nodules	4
1.	Sandstone, gray, massive, with irregular base	34
	Total	346
Black Peaks Formation.		

At most places on Tornillo Flat, the basal sandstone unit of the Hannold Hill Formation rests on the Black Peaks (Pl. IX, nos. 26 and 33), but on the west side, both north and south of the Grapevine Hills, the Hannold Hill lies directly on the Javelina Formation. This indicates that the Hannold Hill overlaps the Black Peaks westward or that the Black Peaks was eroded prior to deposition of the Hannold Hill Formation.

Pulliam Peak.—Tertiary rocks, 373 feet thick, possibly the Hannold Hill Formation, crop out on the north side of Pulliam Peak (Pl. II; N, 16). The basal unit is a gray-white, cross-bedded sandstone, 38 feet thick, with unidentifiable mammal bones. The sandstone has an irregular base and was deposited in a channel in the Javelina; it is most like the Exhibit Sandstone on Tornillo Flat. Above the basal sandstone is gray and maroon nodular clay, mostly covered, followed by a massive yellow sandstone, probably the basal member of the Canoe Formation. A section follows (Pl. IX, no. 24).

Section of probable Hannold Hill Formation (measured by planetable) on the northern side of Pulliam Peak (Pl. IX, no. 24).

		Thickness (Feet)
Canoe(?) Formation.		
Unconformity.		
Hannold Hill (?) Formation—		
8.	Clay, maroon and gray, with calcareous nodules	28
7.	Sandstone, gray to gray white	10
6.	Clay, maroon and gray, with calcareous nodules	146
5.	Clay, gray, silty	6
4.	Sandstone, gray, cross-bedded	12
3.	Clay, gray and maroon, with calcareous nodules	13
2.	Covered, probably clay	119
1.	Sandstone, gray white, cross-bedded, deposited in a channel in top of the Javelina Formation; contains unidentifiable bone fragments. May be same as Exhibit Sandstone Member at Tornillo Flat	38
	Total	372
Unconformity.		
Javelina Formation.		

The Basin.—A well drilled during 1947 in the Basin of the Chisos Mountains (Pl.

II; L, 16) penetrated a sequence much like the exposed section on the north side of Pulliam Peak. The sequence, compiled from drill cuttings, is plotted in Plate X, no. 43. Although precise correlation is impossible, the similarity in thickness of intervals between major sandstone units and the general character of the lithology suggest the presence of upper Hannold Hill beds.

FOSSILS AND AGE

The following vertebrate fossils were identified from the Hannold Hill Formation:

Coryphodon sp.
Hyracotherium vasacciense
Phenacodus cf. *P. primaevus*
Lambdotherium sp.

The vertebrates from the Hannold Hill are Lower Eocene (Wasatchian) age. Invertebrate fossils seem to be absent, but silicified wood is common throughout most of the formation. The preserved structures in the wood (probably angiosperma and gymnosperma) cannot be distinguished from those in the Black Peaks, Javelina, and Aguja Formations.

BIG BEND PARK (New) GROUP

The Tertiary volcanic rocks exposed in Big Bend National Park are designated the Big Bend Park Group. The group comprises, in ascending order, the (1) Canoe Formation, (2) Chisos Formation, and (3) South Rim Formation. These are formed of massive coarse conglomerate, sandstone, clay, fresh-water limestone, tuff, tuffaceous sandstone and clay, flow breccia, and lava. The basal beds are sandstone and conglomerate but above these the amount of volcanic material increases. The upper units (South Rim Formation) are virtually all lava and flow breccia. A complete uninterrupted section is not preserved, and the thickness and lithology of these units vary greatly. Only the basal unit, the Canoe Formation, has been precisely dated.

Canoe (New) Formation

GENERAL FEATURES

The Canoe Formation is named for Canoe Valley in northeastern Tornillo Flat (Pl. II; S, 20–21), where its basal unit is folded into a canoe-shaped syncline (fig. 67). The formation includes massive sandstone, conglomeratic sandstone, cross-bedded sandstone, red, purple, gray and maroon clay and mudstone, gray and gray-white calcareous tuff, indurated vitric tuff, and basaltic lava.

Big Yellow Sandstone Member (new).—The basal unit is a massive yellow sandstone, 30 to 50 feet thick, which is named the Big Yellow Sandstone Member from Big Yellow arroyo in southern Tornillo Flat (Pl. II; P, 21–22). The Big Yellow Sandstone has irregular base and occupies channels in the Hannold Hill Formation (fig. 68). It is commonly conglomeratic, and the pebbles, up to 6 inches across, include igneous rocks, dark chert, and novaculite. It forms ledges and buttes along the west side of Tornillo Flat, low cuestas southeast of the Grapevine Hills, and looks like the ledge-forming sandstone in the Aguja, but it contains igneous pebbles not found in the Cretaceous sandstones as well as mammalian teeth and bones.

Other units.—Above the Big Yellow Member is as much as 1,129 feet of clay, tuffaceous clay and mudstone, sandstone and conglomeratic sandstone, calcareous tuff or tuffaceous limestone, and silicified tuff. This part of the formation is much the same color as the Hannold Hill, Black Peaks, and Javelina Formations, but unlike the underlying formations most of its beds are distinctly tuffaceous. Some of the tuffs have been extensively replaced by calcite and some are chalcedonic. The thickest section of these beds is at the type locality, northeast of the abandoned rock



Fig. 68. Big Yellow Sandstone, with irregular base, resting on clay in the Hannold Hill Formation, Tornillo Flat (Pl. II; Q, 21).

A, Hannold Hill Formation, partly covered with debris from above. B, Big Yellow Sandstone Member.

crusher (Pl. II; P–Q, 21) on the southern edge of Tornillo Flat (fig. 69).

Local lavas within the Canoe Formation are basalts. Individual flows are 17 to 61 feet thick near the type locality, where they are deformed by the McKinney Hills intrusion, and are 250 and 575 feet, respectively, above the base of the formation. Near the head of Estufa Canyon (Pl. II; N, 21), two basaltic lava flows are near the top of the Canoe, and north of Pulliam Peak a basalt consisting of several flows is more than 100 feet thick. Later field and laboratory studies may show that these flows are the same age as the Alamo Creek Basalt southwest of the Chisos Mountains, but a definite correlation between the isolated lavas is not possible at this time (pp. 115–116).

LOCAL FEATURES

Southeastern Tornillo Flat.—The Canoe section at the type locality is 1,161 feet thick. The Big Yellow Sandstone Member is 32 feet thick and is yellowish-gray, cross-bedded, fine-grained sandstone with conglomerate at the base (fig. 69). The base is irregular and is unconformable on gray and maroon clay at the top of the Hannold Hill Formation. About 275 feet of beds immediately overlying the Big Yellow Sandstone are covered, but higher up the sequence is alternating clay, mudstone, tuffaceous clay and mudstone, calcareous tuff, vitric tuff, sandstone and conglomerate. The top beds are fresh-water limestone that are capped by the terrace gravel deposits extending eastward from the Chisos Mountains. A section follows (Pl. IX, no. 28).

Type section of Canoe Formation (measured by planetable) about half a mile north of the abandoned rock crusher site (Pl. IX. no. 28).

	Thickness (Feet)
Terrace gravel (Quaternary?)	
Canoe Formation—	
49. Limestone, gray, siliceous, fine	




C



FIG. 67. Canoe-shaped syncline from which the name Canoe Formation was taken.



FIG. 69. Basalt, tuff, tuffaceous clay, and sandstone conglomerate in the Canoe Formation at the type locality, southeastern Tornillo Flat (Pl. II; P-Q, 21).
A, Fault trace. B, Big Yellow Sandstone Member. C, Basalt

		Thickness (Feet)
	grained, containing a few snails (*Helix* sp.)	7
48.	Sandstone and conglomerate, gray and brown	12
47.	Sandstone, dark gray and greenish, with moderation varying both laterally and vertically, containing nests and stringers of conglomerate, whose pebbles include basalt pebbles as much as 1½ inches across	44
46.	Sandstone, conglomeratic, brownish gray, fine to medium to coarse grained	3
45.	Clay and mudstone, reddish gray, hard and soft beds, tuffaceous, alternating with sandstone	22
44.	Sandstone, red	4
43.	Mudstone, red and reddish gray, tuffaceous	15
42.	Sandstone, reddish gray, tuffaceous, pebbly, conglomeratic at base and containing basalt pebbles up to 1½ inches across	8
41.	Mudstone, reddish gray and salmon (looks red from distance), tuffaceous, in alternating hard and soft layers, conglomeratic sandstone at base	29
40.	Mudstone, reddish gray, tuffaceous	22
39.	Tuff, reddish brown, silicified (chalcedony)	3
38.	Mudstone, reddish brown, tuffaceous	8
37.	Mudstone and tuffaceous mudstone, red and salmon	32
36.	Tuff, gray, indurated, vitric	5
35.	Mudstone, gray, tuffaceous, forming a ledge	2
34.	Mudstone, gray and red mottled, tuffaceous, with two layers of sandstone	18
33.	Mudstone, red, tuffaceous, forming a ledge	4
32.	Clay, gray, salmon, and purple, tuffaceous, with ledge-making beds of tuffaceous mudstone, calcareous tuff (virtually limestone), and vitric tuff as much as 1½ feet thick; a few thin beds of tuffaceous sandstone	111
31.	Tuff, salmon, indurated	1
30.	Clay and mudstone, gray	15
29.	Mudstone, brownish, tuffaceous, forming a ledge	4
28.	Mudstone, salmon	9
27.	Breccia, green, soft, calcareous	1
26.	Clay, gray, salmon, and purple, and tuffaceous clay with sandstone ledge, 2 feet thick, 17 feet above base	28
25.	Sandstone, greenish, coarse grained, tuffaceous, pebbly at base	21
24.	Tuff, dark chocolate to reddish brown, indurated (mappable bed)	6
23.	Clay, gray, tuffaceous, with local tuff beds	44
22.	Clay, dark purplish, tuffaceous, with a few ledges of hard, tuffaceous mudstone	15
21.	Mudstone, gray to drab, tuffaceous, with cobbles of light-gray and purple tuff as much as 2 inches across. At base, breccia with soft, angular, calcareous fragments	40
20.	Tuff, gray, indurated	6
19.	Tuff and tuffaceous limestone, purplish, calcareous, with rounded masses of gray tuff up to 2 inches across	43
18.	Tuff, gray mottled with pink and yellow, vitric, on weathering forms nodules a foot across	8
17.	Tuff, gray white and purple, indurated, weathering to nodules	20
	Basaltic dike, 15 feet thick, vertically exposed for about 100 feet.	
16.	Gray and purple clays, calcareous tuff, crystal tuff replaced by calcite, and two fine-grained, tuffaceous sandstone beds	46
15.	Tuff and mudstone, gray white, sandy, calcified, forming ledge	4
14.	Clay, red and maroon mottled	9
13.	Tuff, gray, slightly indurated, pitted, calcareous	35
12.	Tuff, gray, indurated, calcareous, forming ledge	3
11.	Tuff, gray, slightly indurated	30
10.	Tuff, white, indurated, pitted, calcareous, with nodular weathering. Tuff replaced by calcite and now a tuffaceous limestone	1
9.	Clay, purple	15
8.	Sandstone, gray white, pebbly, tuffaceous	4
7.	Clay, gray and purple, tuffaceous, with crusts of gypsum	50
6.	Clay, red and mottled	44
5.	Covered	154
4.	Sandstone, yellowish	10
3.	Covered	102
2.	Clay, purple	12
1.	Big Yellow Sandstone Member—sandstone, yellow, fine grained, cross-bedded, with conglomerate at base	32
	Total	1,161

Angular unconformity.
Hannold Hill Formation.

In an amphitheater eroded from whitish tuffaceous rock (Pl. II; Q, 21), about half a mile northeast of the type locality, is a partial section of the Canoe Formation. Correlation of beds between the "white amphitheater" and the type locality (Pl. II; P–Q, 21) is possible by tracing a chocolate to reddish tuff bed, designated the "mappable bed" (unit 24, p. 109, and Pl. IX, nos. 27–28), between the two areas (p. 110). *Helohyus* cf. *H. lentus* teeth, an unidentifiable genus and species of the family Brontotheriidae, and a small crocodile and turtle fragments were collected from tuff about 525 feet above the top of the Big Yellow Member (Loc. T9). Unidentifiable mammalian teeth and bone fragments were also collected about 400 feet above this. A description of the lithologic units measured at the "white amphitheater" follows (Pl. IX, no. 27).

Partial Canoe section (measured by planetable) at the "white amphitheater" (Pl. II; Q, 21) *on southeastern Tornillo Flat* (Pl. IX, no. 27).

		Thickness (Feet)
Fault.		
Gray tuffaceous clay, probably unfaulted Hannold Hill Formation.		
Canoe Formation—		
15.	Mudstone, gray, tuffaceous, forming a ledge	4
14.	Mudstone and clay, gray, mostly covered	41
13.	Mudstone, gray and maroon, tuffaceous, forming ledges interbedded with similar but less indurated mudstone	14
12.	Mudstone, red, interbedded with gray clay and mudstone, partly covered	71
11.	Conglomerate, dark brownish red	5
10.	Mudstone and clay, red, partly covered	58
9.	Mudstone, brownish, forming a ledge	4
8.	Clay and mudstone, mostly covered	27
7.	Conglomerate, red and dark brownish red, with basalt pebbles	8
6.	Mudstone and tuffaceous clay, gray and purple, mostly covered	83
5.	Tuff, dark chocolate to reddish brown, indurated (mappable bed) equal to unit 24, section 28, Plate IX	4
4.	Clay and mudstone, gray and purplish mottled, with some interbedded tuff, mostly covered	177
3.	Tuff, gray, containing *Helohyus* cf. *H. lentus* teeth and other skeletons (Loc. T9)	6
2.	Clay, tuffaceous clay, and mudstone, gray and purple mottled, with lenses of pebbly sandstone, partly covered	109
1.	Sandstone, gray, tuffaceous, with unidentifiable mammalian teeth and bone fragments	30
	Total	641

Covered.

Immediately east of the abandoned rock crusher site, two basaltic lavas lie in the Canoe Formation, which is here 883 feet thick (Pl. II; P, 21). Identifiable fossils were not found at this locality, but correlation with the section at the "white amphitheater" can be made by tracing a conglomerate bed between the two areas. Lithologic description and thickness of the units follow (Pl. IX, no. 25).

Partial section of Canoe Formation (measured by planetable), east of the rock crusher site (Pl. IX, no. 25).

		Thickness (Feet)
Covered by alluvium of eastern slope of Chisos Mountains.		
Canoe Formation—		
29.	Mudstone, red, forming a ledge	4
28.	Clay and mudstone, gray and red	19
27.	Clay and mudstone, grayish brown	4
26.	Mudstone, gray brown, interbedded with indurated nodular gray clay	35
25.	Conglomerate, dark brownish red, with igneous pebbles as much as 3 inches across, channel at base. Equal to bed 7, Plate IX, no. 27	8
24.	Mudstone, red	44
23.	Mudstone, red, forming a ledge	4
22.	Clay, red, and platy, gray mudstone	31
21.	Mudstone, gray white, tuffaceous, forming a ledge	4
20.	Clay, gray and maroon	20
19.	Sandstone, gray, platy, slightly conglomeratic	9
18.	Clay, gray and maroon	26
17.	Mudstone, gray white, tuffaceous, forming a ledge	8
16.	Clay and mudstone, red and gray	39
15.	Basalt porphyry flow with feldspar phenocrysts	61

14.	Clay and mudstone, maroon and gray, partly covered	58
13.	Covered	92
12.	Clay, gray, tuffaceous, nodular	10
11.	Sandstone, gray, tuffaceous	6
10.	Clay, gray, tuffaceous, nodular	37
9.	Clay, gray and maroon, tuffaceous	18
8.	Clay, gray and maroon, mostly covered	74
7.	Clay, gray and maroon	12
6.	Basalt flow	17
5.	Clay, maroon and gray, mostly covered	108
4.	Sandstone, white, tuffaceous	3
3.	Clay, gray	96
2.	Clay, yellow, with calcite concretions	8
1.	Big Yellow Sandstone Member—sandstone, yellow, fine grained, cross-bedded, with conglomerate at base. Pebbles are well-rounded chert and novaculite that range up to 4 inches. Forms prominent hogback	28
	Total	883

Angular unconformity.
Hannold Hill Formation.

The Canoe Formation thins north-northwest from the type locality across Tornillo Flat (Pl. IX). Whether the thinning is due to nondeposition, post-Middle Eocene erosion, or a combination of both, is undetermined. The Big Yellow Member is resistant to erosion, usually caps ridges or buttes, commonly is the only part of the formation exposed north of the Park road, and forms the rough hilly belt that borders Tornillo Flat on the southwest. It underlies the lower part of the escarpment at Hannold Hill (Pl. II; P, 21) and extends westward to near the flank of the Grapevine Hills uplift (Pl. II; P–Q, 20). From there, the Big Yellow Sandstone Member forms the cap rock of ridges and buttes that extend northeast and east toward the fossil exhibit. Identifiable fossils are rare in most Big Yellow outcrops.

Northern Tornillo Flat.—The Big Yellow Member is 38 feet thick in northern Tornillo Flat, where it forms the cap rock on the Canoe syncline (Pl. II; S, 20). It rests unconformably upon Hannold Hill beds in the limbs of the fold (fig. 67) and is a yellowish, coarse-grained, cross-bedded sandstone (Pl. IX, no. 32). Mammalian remains include one *Hyrachus* sp. tooth and miscellaneous bone fragments from which the Middle Eocene age of the sandstone was determined (Loc. T8). Higher Canoe beds are not present here.

Estufa Canyon.—Clay, tuffaceous clay and mudstone, tuff, tuffaceous sandstone, and two basaltic lavas crop out along the drainage northwest of Estufa Canyon (Pl. II; N, 20–21). No diagnostic fossils were found, but the sequence probably correlates with the middle part of the Canoe east of the rock crusher (Pl. II; P, 21); it is plotted as section no. 25 on Plate IX.

Nugent Mountain.—Gray, purple, and mottled clay, tuffaceous clay, mudstone, and siltstone crop out east-northeast and north of Nugent Mountain (Pl. II; L, 20). These rest on clay and sandstone containing dinosaur bones and underlie typical Chisos Formation. No fossils have been found. The tuffaceous clay and mudstone are more akin to some beds in the upper Canoe than to other Tertiary formations; they may be the upper part of the Canoe Formation and younger than the beds in Tornillo Flat.

Tortuga Mountain.—In a domelike uplift surrounding the Tortuga Mountain intrusion (Pl. II; H–J, 17) is about 200 feet of dark-gray and brownish clay or mudstone, slightly baked, which is between the Chisos and Aguja Formations and contains *Inoceramus cummingsi.* Fossils have not been collected from these rocks, and they could be a baked equivalent of the beds exposed near Nugent Mountain.

Pulliam Peak.—In the lower foothill slopes on the northern side of Pulliam Peak (Pl. II; M–N, 15–16) is about 580 feet of gray and maroon clay, tuffaceous clay and mudstone, tuffaceous sandstone, conglomerate, and one lava. At the base is a massive yellow conglomeratic channel sandstone containing mammalian bone fragments that is tentatively correlated with the Big Yellow Member. Mammalian teeth believed to be of Middle Eocene age and a turtle bone were collected from a sandstone

about 260 feet above the Big Yellow Sandstone Member (?). These beds differ from the overlying Chisos beds. They are most like Canoe Formation in Tornillo Flat.

The Basin.—Previous reference (p. 96) has been made to a well in the Basin which penetrated a sequence of alternating sandstone and clay below exposures of the Chisos Formation. Data compiled from drill cuttings are plotted on Plate X, section 43. The upper part of the sequence is probably Canoe Formation.

FOSSILS AND AGE

Teeth from *Helohyus* cf. *H. lentus, Hyrochyus* sp., and the family Brontotheriidae were collected from the Canoe Formation and are the basis for assignment of a Middle Eocene age. The fresh-water snail *Helix* sp. was found in some beds. Abundant silicified wood occurs in some places but it could not be distinguished from the wood found in the underlying Tertiary formations. Turtle and crocodile remains are found in some places.

Chisos Formation

GENERAL FEATURES

The Chisos Beds (Chisos Formation of this report) were named and described by Udden (1907a, pp. 60–66) from outcrops in the Chisos Mountains, southern Brewster County, Texas, where they are approximately 3,500 feet thick. The Chisos Formation is composed of massive conglomerate, coarse-grained sandstone, fine- to medium-grained tuffaceous sandstone, tuffaceous clay and mudstone, tuff, indurated tuff, and lava. The sequence varies greatly in thickness and lithology from place to place.

The thickest section of Chisos Formation (3,438 feet) is exposed on the east side of Pummel Peak (east side of Chisos Mountains, Pl. II; M, 19), but the formation changes rapidly westward in both thickness and lithology. The basal 2,000 feet east of Pummel Peak (Pl. X, no. 45) is mostly fine clastic rocks, including fine-grained tuffaceous sandstone. Most beds are light gray, well stratified, in 1- to 2-foot beds (fig. 70). The upper 1,500 feet is coarser (Pl. X, no. 45) and is mostly gray and bluish-gray, coarse-grained sandstone with beds and lenses of tuffaceous clay and mudstone and massive conglomerate. The 200 feet of beds immediately beneath the lowest lava are all coarse-grained sandstone interbedded with massive conglomerate. Some of the conglomerates contain cobbles of Comanchean limestone as much as 6 inches across and lava boulders as much as a foot across (fig. 71). Udden (1907a, pp. 66–67) termed these the Crown Conglomerate.

A different lithology of the Chisos Formation occurs south, southwest, and west of the highest Chisos Mountains peaks. This western facies begins at the north end of Burro Mesa (Pl. II; N, 12) and extends southward to beyond the Rio Grande. The western Chisos Formation facies is a sequence of lava, tuff, and tuffaceous clay, most of which is absent in the Pummel Peak area (Pl. X). Several of the lava flows in the western facies have only limited lateral extent and are probably of local origin, but four flows and one indurated tuff bed are more extensive and are designated as named members. In ascending order these are (1) Alamo Creek Basalt; (2) Ash Spring Basalt; (3) Bee Mountain Basalt; (4) Mule Ear Spring Tuff; and (5) Tule Mountain Trachyandesite. The five members are interbedded with variable thicknesses of clay and mudstone, tuffaceous clay and mudstone, tuff (in part well indurated), tuffaceous sandstone, coarse massive conglomerate, very thick lenses of fanglomerate, and some fresh-water limestone (fig. 72). One or more erosion surfaces separate all of the members and some of the older members are overlapped by younger units.

The three basalt members are all so similar that it is difficult to identify them except where the stratigraphic sequence is preserved, and positive field identification is impossible where only one basalt is



FIG. 70. Fine- to medium-grained tuffaceous sandstone (50 feet thick) in the Chisos Formation east of Pummel Peak.



FIG. 71. Massive conglomerate in upper Chisos Formation, "Crown Conglomerate" of Udden (1907a, pp. 66–67). The larger boulders are about a foot across.



Fig. 72. Tuff, tuffaceous clay, mudstone, and lava sequence in the Chisos Formation, southwestern Chisos Mountains.

A, Cerro Castellan, capped by South Rim lava. B, Terlingua fault escarpment. C, Santa Elena Canyon. D, Mule Ear Spring Tuff. E, Bee Mountain Basalt. F, Tuffaceous clay and sandstone.

present. In marked contrast to the similar lithologic characteristics of the basaltic lavas, the Tule Mountain Trachyandesite and Mule Ear Spring Tuff are distinctive.

Field examination of the lavas was supplemented by microscopic study of hundreds of rock specimens, by chemical analyses of a few, and by paleomagnetism studies, the latter by J. D. Martinez, then with the Humble Oil & Refining Company, in cooperation with the Bureau of Economic Geology. Potassium-argon determinations of some lavas were made by J. H. Halsey, Socony Mobil Oil Company, and J. F. Evernden, University of California.

The base of the Chisos Formation is unconformable to the older rocks on which it rests. The eastern facies lies upon the Canoe Formation east and southeast of the highest peaks, at Tortuga Mountain, in the Basin, and north of Pulliam Peak. Along the west side of the highest peaks, the Alamo Creek Basalt, lowest member of the western facies, lies upon an erosion surface in the Javelina. There is a conspicuous erosion surface at the top of the Chisos Formation, and the overlying South Rim Formation truncates both the eastern and western facies.

There is some suggestion that the basal beds of the western Chisos Formation facies correlate with the uppermost Canoe Formation on southwestern Tornillo Flat. There are basaltic lavas in both areas (p. 108) and mammalian teeth and bones from above the basalt in the "white amphitheater" and near Cerro Castellan, southwest of the Chisos Mountains, are Bridgerian. It has been impossible to correlate the basalts and there is only a slight similarity in the overlying rock units (see sections 25, 26, 27, and 28, Pl. IX, and sections 36, 37, 38, and 39, Pl. X). The rock sequence was

subdivided into lithostratigraphic units based on the relations of the Canoe and Chisos Formations where these rocks crop out along the east side of the Chisos Mountains. If future work reveals that this contact should be revised, the Chisos-Canoe formational contact will probably be placed at the base of the lowest basalt shown in section 25, Plate IX.

DESCRIPTION OF NAMED MEMBERS

Alamo Creek Basalt (new)—The Alamo Creek Basalt Member is named from Alamo Creek west of the Chisos Mountains (Pl. II; K–L, 9) where the lava is exposed almost continuously from near Dawson Creek southward to the Rio Grande (fig. 73). It is the lowest unit of the western Chisos Formation facies and does not extend east of a structural and topographic barrier that is near a line drawn from the high part of the central Chisos Mountains southeastward along the crest of the Cow Heaven anticline. This barrier seems to have arrested the eastern movement of the Alamo Creek Basalt flow and perhaps also accounts for the absence of Lower Eocene and Paleocene rocks in the western part of the Park. Uplift and erosion along this line are indicated at the north end of the Cow Heaven anticline (Pl. II; G, 16) where the Javelina Formation and about half of the Aguja Formation were eroded and part of the Chisos Formation above the Alamo Creek Basalt Member lies directly on the Aguja. At Tortuga Mountain (Pl. II; J–H, 17) Chisos beds above the Alamo Creek Basalt lie on about 200 feet of Canoe Formation which truncates middle Aguja. Similar conditions were observed in the Basin (Pl. II) where the Javelina and upper Aguja are absent and well cuttings indicate that Chisos Formation above the Alamo Creek Basalt Member rests on Canoe Formation. Everywhere in the west-



Fig. 73. Upper Alamo Creek, looking southeastward toward the Chisos Mountains. Alamo Creek Basalt and overlying volcanic sequence rest on Javelina Formation.

A, Javelina Formation. B, Alamo Creek Basalt. C, Tuff beds in the Chisos Formation.



Fig. 74. Lajitas Mesa with ruins of the old United States Military Post in the foreground. A, Pen Formation. B, Alamo Creek Basalt. C, Tule Mountain Trachyandesite capping Lajitas Mesa.

ern part of the Park the Alamo Creek Basalt Member lies on an eroded surface in the Javelina Formation, but it truncates older rocks down to the San Vicente Member toward the northwest (fig. 74).

Most of the Alamo Creek Basalt is a fine-grained, hard, dark lava. Locally, there are small phenocrysts. The base is usually scoriaceous, and commonly it contains inclusions that were picked from the underlying bedrock (fig. 75). It is 20 to 208 feet thick in the measured sections (Pl. X). The thickest exposures are southwest of the highest Chisos Mountains peaks, in the Round Mountain—Kit Mountain—Cerro Castellan area (Pl. II; G–H, 9–11); the lava thins northward, northwestward, and southeastward from that area. Part of the thinning is due to erosion as there are channels and a well-developed erosion surface on top of the lava at some places. The vent from which the lava came has not been located, but it may be in the southwestern part of the Park or nearby Mexico.

Paleomagnetic properties of the Alamo Creek Basalt from three locations were studied by Martinez et al. (1960, p. 35). Remnant magnetization in eight samples from the three localities agrees with the present dipole field. However, two samples from the oldest flow on the northeast corner of Black Mesa (Pl. II; K, 10) show divergent data which have not been explained.

Ash Spring Basalt Member (new).—The second lava above the base of the Chisos Formation is named the Ash Spring Basalt for Ash Spring (Pl. II; N, 15) on the northwest side of the Chisos Mountains where it forms a massive ledge (fig. 76). The member is conspicuously porphyritic (fig. 77) with phenocrysts of plagioclase, some more than half an inch long, at the type locality. The coarse porphyritic texture is characteristic throughout the



FIG. 75. Typical Alamo Creek Basalt outcrop, along Alamo Creek.



FIG. 76. Type locality of the Ash Spring Basalt, on north side of the Chisos Mountains. A, Ash Spring Basalt. B, Tule Mountain Trachyandesite. C, Wasp Spring Flow Breccia. D, Pulliam Peak intrusion.



FIG. 77. Ash Spring Basalt at the type locality (Pl. II; N, 16).

eastern extent of the member, but westward the phenocrysts are smaller and less abundant. In the western extent of the member, where the unit consists of two or more flows, the upper part of each flow is vesicular and frothy, but the middle part of the flow is dense porphyritic basalt with plagioclase phenocrysts ⅛ to ¼ inch long. At all exposures, the basal 10 feet is scoriaceous and many of those openings are filled by secondary minerals.

The Ash Spring Member is from 65 to 200 feet thick in the measured sections (Pl. X). At all localities studied, where it is more than 50 feet thick, it consists of two or more flows. The basal unit truncates older Chisos beds and at some places the lava occupies an old stream valley. The upper surface was also eroded prior to deposition of the younger Chisos Formation. The post-Ash Spring erosion no doubt accounts for some of the variations in thickness but there is also a general thinning from the northern side of the Chisos Mountains southwestward toward the Rio Grande. The greatest thickness (200 feet) is near Ash Spring, which may be close to the source of the lava, but it thins both east and west and also south from that locality. One of the intrusions north of Pulliam Peak might have fed the lava, but the vent has not been located.

The Ash Spring Member is so strongly magnetized that it affects field readings with a Brunton compass. Martinez et al. (1960, p. 35) determined the magnetic field of 21 samples from 7 localities. These show a wide scatter of dipole directions from place to place and considerable variation between samples at the same location. This scatter appears to be characteristic of the formation. The principal exception to the scatter pattern was obtained from samples at the measured section on the north side of Pulliam Peak (Pl. II; N, 16). These samples were fairly consistently magnetized in an inverse direction to the normal dipole field similar to the overlying Bee Mountain Basalt.

Bee Mountain Basalt Member (new).—



FIG. 78. Bee Mountain (at left), the type locality of the Bee Mountain Basalt (Pl. II; J–N, 9–10). The Bee Mountain Basalt caps the mesa on the right (west), and the outcrop can be traced to the left (east) into the lower slopes of Bee Mountain.



FIG. 80. Type locality of the Mule Ear Spring Tuff (Pl. II; G, 12).
A, Mule Ear Spring Tuff. B, Tule Mountain Trachyandesite. C, Bee Mountain Basalt.

The Bee Mountain Basalt is named from Bee Mountain (Pl. II; H–J, 9–10) on the western side of which the member is exposed (fig. 78). It is the most extensive basalt member in the Chisos Formation, is present at many places west and southwest of the Chisos Mountains, and is traceable from the lowlands eastward into the Chisos Mountains where it is the lowest lava in the high peaks. The member also extends southward from the Park into Mexico, northwestward into the southeastern foothills of the Bofecillos Mountains, and is present in Black Gap east of the Sierra del Carmen.

The basalt is mostly fine to medium grained, consisting of several flows that are conspicuously scoriaceous or vuggy along contacts (fig. 79). Many of the scoriaceous openings are filled by secondary minerals which produce a mottled appearance. At Bee Mountain several flows are separated by 1- to 6-inch tuff beds and vesicular areas. The basal 1 to 3 feet of each flow is brecciated and the fractures are filled by quartz, including some well-developed crystals. Irregular small quartz veins are common. On the west side of Burro Mesa (Pl. II; L, 12) lenticular tuffaceous clay, 24 feet thick, is incorporated in the lava (Pl. X, no. 40) and at Casa Grande (Pl. II; L, 16) two basalt flows are separated by 12 feet of tuffaceous sandstone (Pl. X, no. 43). On the north side of Blue Creek (Pl. II; K, 14) indurated tuff beds separate two flows and along Smoky Creek (Pl. II; D, 12) conglomeratic sandstone lenses are between two flows.

The Bee Mountain Member is about 25 to 80 feet thick in the higher Chisos Mountains, but the thickness increases southwestward to 527 feet at Cerro Castellan (Pl. II; G, 10; Pl. X). Here the lava is especially scoriaceous and has many cavities as much as 12 inches across, some filled by secondary minerals; there is very irregular flow structure. There is some suggestion that the Bee Mountain Basalt came from a nearby vent but the vent or vents have not been located.

The Bee Mountain Basalt lies on an erosion surface in the Chisos Formation. At the east side of Pummel Peak (Pl. II; M, 19), the Bee Mountain Member lies on about 200 feet of sandstone and conglomerate. Erosion reduced the thickness of the coarse clastic rock interval toward the south and southwest. At Bee Mountain, the conglomeratic rocks are only about 20 feet thick and at some places the conglomerate is absent. An erosion surface is also present at the top of the Bee Mountain Basalt. At places there are channels cut in the lava, and at Tule Mountain (Pl. II; L, 10), the Bee Mountain is eroded and a massive fanglomerate consisting mostly of Bee Mountain lava boulders fills an extensive valley to a depth below the lava member.

Results of paleomagnetism studies by Martinez et al. (1960, p. 35) indicate that the Bee Mountain Basalt is characterized by inverse magnetism but there is considerable scatter. The greatest scatter is in samples from the top flow at Blue Creek (Pl. II; K, 14) which have magnetic field orientations most like samples studied from lava units that occur above the Bee Mountain Basalt at other localities.

Mule Ear Spring Tuff Member (new). —Tuffaceous rocks are common throughout the Chisos Formation but are most abundant west and southwest of the highest mountain peaks. One of the tuffs is uniform in thickness and lithology and can be traced across the southwestern Park area, is present in Mexico, and extends northwestward into the Bofecillos Mountains and northward where it disappears on the flank of the Solitario. It is named the Mule Ear Spring Tuff Member from Mule Ear Spring (Pl. II; G, 12), 1½ miles northwest of Mule Ear Peaks (fig. 80).

The member is 8 to 12 feet thick and is punky ash to very hard, brittle, silicified tuff with conchoidal fracture. Fresh surfaces are pinkish salmon, brick red, and yellowish gray to bluish gray, but the rock weathers brown. In steep slopes the Mule Ear Spring Member forms a conspicuous, persistent, brick-red band (fig. 81). Where the tuff is silicified and resists erosion, it

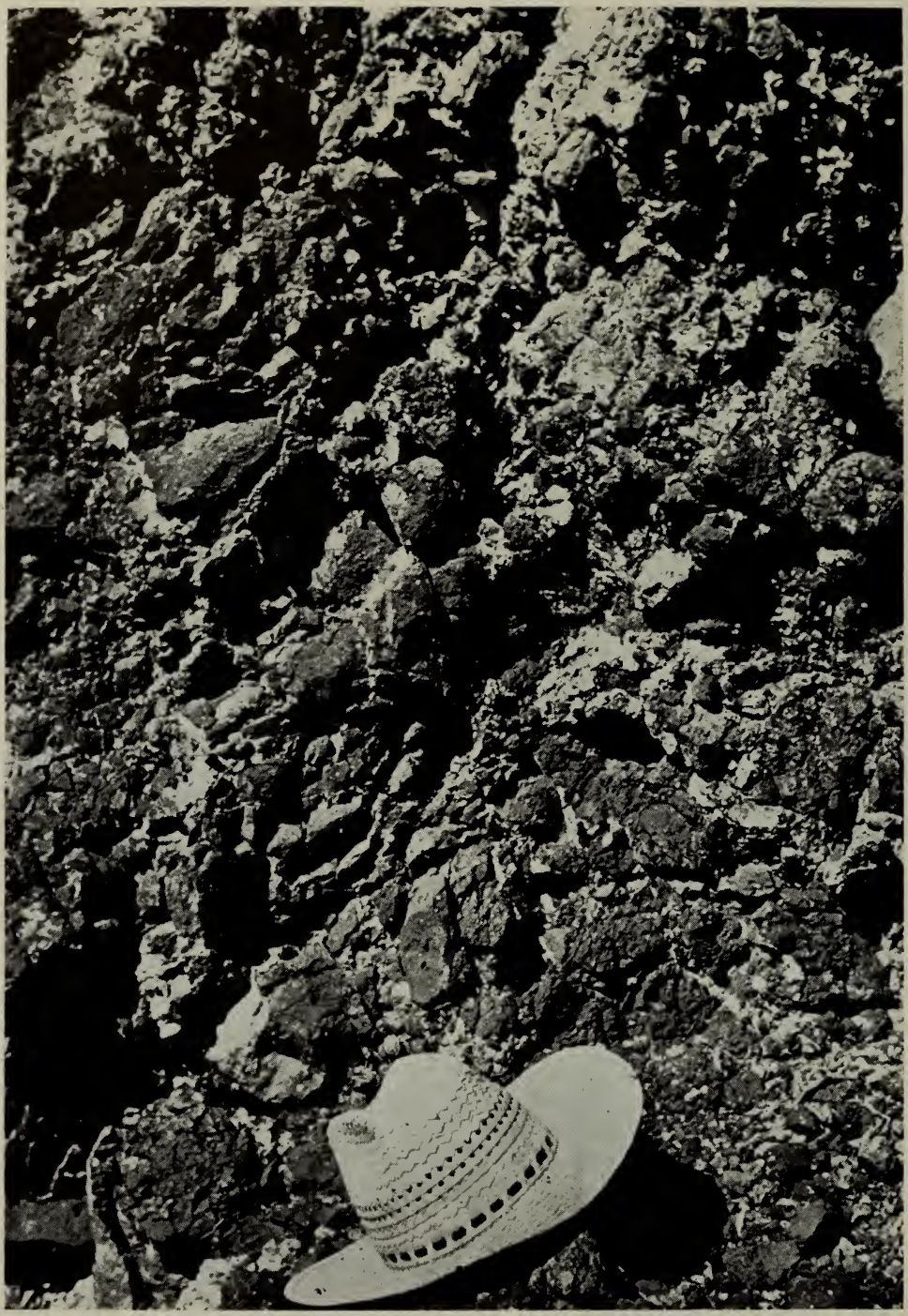


Fig. 79. Scoriaceous Bee Mountain Basalt with conspicuous secondary minerals.



Fig. 81. Mule Ear Spring Tuff in the Chisos Formation along Smoky Creek near Triangulation Station Mountain. Fault is in upper left.

A, Bee Mountain Basalt with tuff lens (A-1). B, Tuffaceous sandstone. C, Mule Ear Spring Tuff. D, Unnamed basalt. E, Tuff band in Chisos Formation. F, Unnamed basalt. G, Tule Mountain Trachyandesite.

commonly underlies a prominent dip slope (fig. 72).

The Mule Ear Spring Tuff truncates middle Chisos beds and probably originated as an ash fall that blanketed a surface of low relief. In some places it rests on the Bee Mountain Member and in others is separated from that member by about 125 feet of tuffaceous rocks in the Chisos Formation. At Tule Mountain it lies directly on the fanglomerate deposits that fill the valley eroded through the Bee Mountain Basalt (Pl. X). Tuffaceous clay and lava units overlie the Mule Ear Spring Tuff at most localities southwest of the Chisos Mountains, but closer to the high peaks, the overlying tuffaceous rocks have been eroded and the next younger lava unit, the Tule Mountain Trachyandesite, lies directly on the Mule Ear Spring Member at Tule Mountain and some places along the west side of Burro Mesa. Locally, the Mule Ear Spring Tuff is also eroded and the Tule Mountain Member rests on the Bee Mountain Basalt.

Tule Mountain Trachyandesite Porphyry (new).—The youngest named member of the Chisos Formation is a brown porphyritic trachyandesite which forms the cap rock on Tule Mountain (Pl. II; L, 10) northwest of the Chisos Mountains and is named the Tule Mountain Trachyandesite Member (fig. 82). The member crops out in many places in the western and southwestern exposures of the Chisos Formation and the lava unit is easily recognized in the field (fig. 83).

In hand specimen the trachyandesite has a gray or brownish-gray, fine-grained groundmass which contains feldspar phenocrysts as much as half an inch across. Most of its weathered surfaces are brown or reddish brown. The groundmass is slightly darker than the phenocrysts and



Fig. 82. Type locality of the Tule Mountain Trachyandesite (Pl. II; L, 10).

A, Tuff and tuffaceous material in Chisos Formation. B, Ash Spring Basalt. C, Massive boulder fanglomerate. D, Mule Ear Spring Tuff. E, Tule Mountain Trachyandesite. F, Line of measured section (Pl. X, no. 41).

produces a distinctive spotted pattern. The member consists of several flows, but flow structure is not prominent, so that it commonly forms a thick massive ledge. Where several flows are recognized, the contacts are purplish, slightly scoriaceous, and commonly tuffaceous. These softer contact zones weather and erode to produce blocky steplike ledges. On the northwestern side of Sierra de Chino (Pl. II; E, 11) and on the west side of Burro Mesa (Pl. II; L, 12), the upper flow or flows are dark brown or almost black, are conspicuously scoriaceous, and especially tough to break.

The Tule Mountain Member ranges in composition from trachyte (containing andesine) to trachybasalt. Trachybasalt occurs only on the northwest side of Sierra de Chino, where it comprises the topmost flow, and locally it makes up the top flow at Burro Mesa (mentioned above). The most abundant rock contains 15 to 20 percent of calcic andesine phenocrysts, 2 to 5 percent smaller phenocrysts or microphenocrysts of clinopyroxene, about 1 percent of magnetite-ilmenite microphenocrysts, and a trace of about 0.5 percent iddingsite (after olivine) phenocrysts. The principal constituent of the groundmass is alkali feldspar, which occurs in laths, commonly with cores of sodic andesine, grains of clinopyroxene or magnetite-ilmenite, and prisms or needles of apatite. The mean groundmass is generally fine grained or aphanitic. The phenocrysts are as much as 6 by 10 mm and are characteristically square. Altered mafic microphenocrysts form small dark grains or aggregates in the coarser-grained rocks.

The trachyandesite is remarkably uniform mineralogically. A few specimens contain a trace of interstitial quartz. A single specimen has a trace of brown amphibole, fluorite has been tentatively identi-



Fig. 83. Looking east toward outcrops of Tule Mountain Trachyandesite from ridge east of Mule Ear Spring. The trachyandesite (A) is prominent and has been stepped-down and repeated by several faults.

fied in one sample, and a few samples contain analcite. The plagioclase includes individual crystals and glomerocrysts. In most specimens the groundmass forms a regular pattern that resembles a perthitic intergrowth. In a few specimens the groundmass is largely alkali feldspar. Many plagioclase phenocrysts are thinly mantled by alkali feldspar, many are zoned, and some zones are sodic labradorite. The average plagioclase is in the andesite range. Some of the clinopyroxenes are minerals; iddingsite phenocrysts and apatite form inclusions in the plagioclase phenocrysts.

Clinopyroxene forms microphenocrysts or very small phenocrysts, 0.5 to 2 mm in diameter. Rare crystals are subhedral to euhedral and many are glomerocrysts rather than individuals. Only one or two remnants of unaltered olivine enclosed in iddingsite were observed. The iddingsite is optically negative and appears to be iron-rich. It is sparse in the trachybasalt but plentiful in some of the more siliceous specimens; it has not been identified in any of the specimens containing interstitial quartz.

Chemical and modal analyses of typical Tule Mountain Trachyandesite are given in table 7 and are also reported in table 14 as numbers 48, 51, 52, 55, 57, 59, 60, 61. Completely fresh material was not found and the analyses are therefore only approximate. In the samples studied, all of the olivine has been converted to secondary minerals, the pyroxenes of the groundmass are nearly all altered, and in some thin sections there are traces of calcite. The alteration accounts for the high ferric oxide content.

The trachybasalt differs from the more siliceous rocks mainly in the amount rather than the kind of minerals. The plagioclase of the phenocrysts is sodic labradorite, the groundmass plagioclase is more abundant and somewhat more calcic, and the microphenocrysts of clinopyroxene, magnetite-

ilmenite, and iddingsite average about 15 percent. Specimens of these rocks are gray to black and the groundmass is dense to aphanitic. Some specimens are more vesicular than the more abundant siliceous types. Chemical and modal analyses from four samples of weathered material are given in table 8, and are also reported in table 14 as numbers 65, 76, 78, and 80.

The Tule Mountain Member is the most prominent lava unit in the Chisos Formation. The maximum thickness measured is 348 feet (Pl. X) but it thins or is missing by erosion in some places. The Tule Mountain Member occurs in Mexico south of Castolon, west of Mesa de Anguila, and in the Fronteriza Mountains south of the Mexico Sierra del Carmen. It forms a promi-

TABLE 7.—Chemical analyses and modes of Tule Mountain Trachyandesite Porphyry. (See also table 14.)

Item No.	48	51	52	55	57	59	60	61
				CHEMICAL ANALYSES				
SiO_2	62.19	61.74	61.38	60.99	60.57	60.20	59.80	59.63
Al_2O_3	15.20	14.96	16.12	16.83	15.18	14.23	14.50	16.01
Fe_2O_3	5.89	6.43	5.04	6.16	5.89	6.66	6.66	5.60
FeO	0.58	0.92	1.48	0.64	1.66	1.16	1.28	0.94
MgO	0.56	0.65	0.86	0.51	0.79	1.15	1.39	1.45
CaO	2.43	2.99	4.15	2.51	3.13	3.48	4.44	3.33
Na_2O	5.25	4.70	4.00	4.89	4.54	4.50	3.91	3.56
K_2O	5.16	4.97	3.32	4.93	4.79	4.24	3.90	4.76
TiO_2	0.77	0.98	1.50	1.04	1.06	0.98	1.70	1.39
P_2O_5	0.19	0.25	0.09	0.22	0.34	0.37	0.43	0.47
MnO	0.10	0.17	0.10	0.10	0.17	0.11	0.11	0.15
Ign. Loss	0.99	1.08	0.74	0.94	1.57	1.82	1.12	1.52
H_2O	0.83	0.45	0.86	0.50	0.73	0.88	0.57	0.81
Totals	100.14	100.29	99.64	100.26	100.42	99.78	99.81	99.62
				MODES				
Groundmass	83.5	63.5	74.4	73.3	74.6	80.0	65.8	....
Plagioclase	14.9	33.8	18.2	21.5	22.0	17.0	26.7	....
Pyroxene	0.8	0.3	5.3	3.9	1.7	1.3	5.5	....
Opaque minerals	0.8	1.8	2.1	1.3	1.5	1.3	2.0	....
Olivine (iddingsite)	....	0.6	....	....	0.2	0.4	....	....
Plagioclase phenocrysts	An_{46}	An_{46}	An_{49}	An_{42}	An_{45}	....	An_{49}	An_{51}
Groundmass plagioclase	....	An_{36}	An_{35}	An_{35}	....	....	An_{36}	An_{35}
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	....

Item No.—

48. West flank of Round Mountain, 25 feet above base. Plagioclase phenocrysts zoned. About one-tenth of groundmass is alkali feldspar laths with plagioclase cores.
51. Lava from Kit Mountain. Plagioclase phenocrysts zoned to An_{36}. Some of the groundmass is alkali feldspar laths and grains with plagioclase cores.
52. Lava from bottom of cap rock, north side of Tule Mountain. About one-half of groundmass is alkali feldspar laths and grains with plagioclase cores.
55. Canyon northeast of Mule Ear Spring. Plagioclase phenocrysts zoned. Minor discrete grains of plagioclase in groundmass.
57. Lava from northeast flank of Triangulation Mountain, 125 feet above base.
59. High lava ledge, north bank of Smoky Creek, 175 feet above base. Plagioclase phenocrysts zoned. About one-half of groundmass is alkali feldspar laths with plagioclase cores.
60. Lava on north end of Burro Mesa. About one-half of groundmass is alkali feldspar laths with plagioclase cores.
61. Lava on northwest flank of Pulliam Peak. Plagioclase phenocrysts zoned. About three-fourths of groundmass is alkali feldspar laths with plagioclase cores.

nent ledge along the southeastern flank of the Bofecillos Mountains, is exposed in small domes within the Bofecillos Mountains, and is prominent along lower Fresno Creek to where it disappears northward against the southwestern flank of the Solitario (Pl. I).

The base of the Tule Mountain Trachyandesite is irregular and rests on an erosion surface in the Chisos Formation. At Kit Mountain (Pl. II; J, 11), southwest of the highest Chisos Mountains peaks, 300 feet of tuffaceous Chisos beds separate the Tule Mountain and Mule Ear Spring Members. At Tule Mountain, northwest of the Chisos Mountains, the Tule Mountain Member lies directly on the Mule Ear Spring Tuff; locally along the west side of Burro Mesa it rests on the Bee Mountain Basalt, farther north it overlaps the Bee Mountain Member, and at Sierra de Chino (south of the Chisos Mountains) it overlaps Chisos beds down to a level about 100 feet above the top of the Alamo Creek Basalt.

The source of the Tule Mountain Trachyandesite is undetermined. A curved dike near the eastern end of Sierra de Chino (Pl. II; D, 13), southern Chisos Mountains, is similar chemically and petrographically to the extrusive Tule Mountain Trachyandesite rocks and may be a source.

TABLE 8.—Chemical analyses and modes of trachybasalt. (See also table 14.)

Item No.	65	76	78	80
	CHEMICAL ANALYSES			
SiO_2	55.96	52.50	51.89	51.39
Al_2O_3	15.78	15.01	14.96	16.18
Fe_2O_3	7.29	9.35	8.72	7.94
FeO	2.88	2.56	2.58	2.04
MgO	1.62	1.81	2.51	1.64
CaO	5.20	6.66	6.79	8.35
Na_2O	4.05	3.90	3.62	3.89
K_2O	3.27	2.84	2.93	2.89
TiO_2	1.77	1.74	1.76	1.97
P_2O_5	0.51	0.53	0.52	0.44
MnO	0.17	0.23	0.12	0.24
Ign. Loss	1.19	2.01	2.33	2.75
H_2O	0.83	1.07	1.47	0.74
Totals	100.52	100.21	100.20	100.46
	MODES			
Groundmass	58.1	56.9	58.5	43.8
Plagioclase	31.1	31.4	31.4	42.4
Pyroxene	4.5	4.8	4.9	7.5
Opaque minerals	3.0	2.3	1.6	1.1
Olivine (iddingsite)	3.3	4.6	3.6	5.2
Plagioclase phenocrysts	....	....	....	....
Groundmass plagioclase	....	....	....	....
Totals	100.0	100.0	100.0	100.0

Item No.—

65. Cap rock on Triangulation Mountain, west of Smoky Creek. Plagioclase phenocrysts zoned, many with pronounced rims of alkali feldspar. Augite anhedral, iddingsite after olivine. Groundmass has stubby laths of alkali feldspar.
76. Lava in Triangulation Mountain. Plagioclase as above. Augite and iddingsite more abundant. Groundmass generally the same.
78. Smoky Creek south of Triangulation Mountain. Plagioclase zoned and perthitic rims inconspicuous. Augite, iddingsite, and opaque minerals. Laths of plagioclase in the groundmass.
80. Lava in Sierra de Chino, about 1 mile east of Smoky Creek. Plagioclase notable, alkali feldspar rims. Augite, iddingsite, and opaque minerals present, and an increase in calcite; otherwise, the rock is about the same as the preceding items.



FIG. 84. Section of Chisos and South Rim Formations measured on east side of Pummel Peak (Pl. X, no. 45). A, Line of measured section. B, Chisos Formation. C, South Rim Formation.

Certain structures in the central Chisos Mountains are suggestive of a collapsed caldera but conclusive evidence of a vent that may have fed the Tule Mountain flows has been obliterated by post-Chisos Formation erosion or younger extrusive and intrusive activity. The maximum thickness of the lava is at Kit Mountain (Pl. II; J, 11) but there is no evidence of a vent in that area. The thickness of the Tule Mountain Member decreases in all directions away from Kit Mountain but at least part of that thinning is due to subsequent erosion. The trachyandesite probably extended over a much larger area than its present outcrops and it probably came from several vents in widely separated areas.

Martinez et al. (1960, pp. 37–38) measured paleomagnetic properties of 14 samples from 6 localities. The results showed considerable scatter of magnetic vectors as compared with the direction of the earth's present magnetic field. The scatter may be due to (1) sampling from different flows or different levels in the same flow; (2) differential movement of consolidated parts of a thick lava that hardened at temperatures below the average for the Curie point of the entire mass; and/or (3) the rock may be magnetically unstable so that the magnetic field of samples from some individual flows is drifting back toward the direction of the earth's present magnetic field.

LOCAL FEATURES

Higher Chisos Mountains area.—The Chisos Formation is extremely varied in both thickness and lithology (pp. 112–115 and Pl. X). The boundary between the eastern and western facies is near the trace of the Burro Mesa fault to its southern terminus, thence southeastward in an arc near the west side of the Sierra Quemada and Dominguez Mountain intrusions. The



FIG. 85. Looking northward at the South Rim. Chisos Formation in foreground is unconformably overlain by the South Rim Formation at top of rim.

A, Approximate course of section in Plate X, no. 44 (Pl. II; J-K, 16). B, Chisos Formation. C, Lava and flow breccia unit in the South Rim Formation.

two facies interfinger across this boundary, but the beds to the east are mostly thick massive conglomerate, well-bedded tuffaceous sandstone, relatively small amounts of tuff or clay, and no lava flows. The beds to the west are mostly tuffaceous clay or mudstone, tuff, lava, and a relatively small amount of sandstone and massive conglomerate (Pl. X).

The thickest known sequence, eastern facies, of Chisos Formation (3,438 feet) is on the east side of Pummel Peak (Pl. II; M–N, 19–20) where locally the South Rim Formation lies on the Chisos Formation that dips as steeply as 45° (fig. 84). The basal relations with the Canoe Formation are not clear (p. 111). On the east side of Pummel Peak the basal Chisos unit is a sandy conglomerate with limestone pebbles. Elsewhere the lowest sandstones are only slightly conglomeratic, there is no sharp lithologic change, and the contact is gradational. Udden (1907a, p. 65) referred to this contact as an "horizon of change" between his Tornillo Clay and the Chisos Beds (the writers' Canoe and Chisos Formations). A similar sequence with the same basal relations occurs between Nugent Mountain and the south end of Pummel Peak and at Tortuga Mountain. As much as 2,950 feet of Chisos Formation occurs between Tortuga Mountain (Pl. II; J–K, 16) and the South Rim, and many of the stratigraphic units of the Pummel Peak area are recognized (fig. 85). In Blue Creek Canyon, below the west end of the South Rim (Pl. II; J–K, 15), the Chisos Formation has been deformed and repeated in the Burro Mesa fault system. The sequence is not complete nor continuous and the base is not exposed, but approximately 2,000 feet of Chisos Formation occurs from slightly above the Bee Mountain Basalt to a level about 200 feet

below the Ash Spring Basalt. The principal difference between the beds exposed in Blue Creek Canyon and at Pummel Peak is that the coarse clastic rocks as exposed at the top of the formation in the eastern facies are thin at Blue Creek Canyon and two lava units from the western facies are present.

Description and thickness of the lithologic units in the eastern slope of Pummel Peak follow (Pl. X, no. 45).

Section of Chisos beds (measured by plane-table) on the eastern slope of Pummel Peak (Pl. X, no. 45).

		Thickness (Feet)
	South Rim Formation.	
	Angular unconformity.	
	Chisos Formation—	
50.	Covered by coarse debris from peak above, probably underlain by Chisos Formation	45
49.	Bee Mountain Basalt Member—basalt, black, crumbly	25
48.	Sandstone, reddish, slightly baked at contact, grading downward into coarse-grained sandstone and into conglomerate toward base	87
47.	Conglomerate, gray and brown, with lava cobbles and boulders as much as 12 inches across	37
46.	Sandstone, gray to bluish gray, coarse grained, with conglomerate lenses containing cobbles as much as 6 inches across	78
45.	Sandstone, gray to bluish gray, massive, coarse grained	103
44.	Sandstone, gray, blue gray, and light brown, with clay lenses, partly covered	228
43.	Sandstone, gray and bluish gray, coarse grained, pebbly, containing conglomerate lenses with igneous cobbles as much as 6 inches across	70
42.	Sandstone, gray and blue gray, coarse grained, and 15-foot bed of gray and light-brown conglomerate, containing many cobbles and boulders of dull-gray feldspar porphyry as much as 12 inches across	335
41.	Sandstone, gray, conglomeratic	35
40.	Sandstone and mudstone, gray, light bluish gray, and light brownish, containing lenses of coarse-grained sandstone and conglomeratic sandstone with igneous pebbles	440
	Sill, basalt, 11 feet thick.	
39.	Tuff, white and gray white, appearing like limestone	73
	Sill, basalt, 15 feet thick.	
38.	Tuff, gray white	16
37.	Mudstone, gray, tuffaceous	27
36.	Tuff, gray white, with beds of dark green hackly mudstone	42
35.	Mudstone, gray green	30
34.	Tuff, gray	40
33.	Mudstone, gray, tuffaceous	10
32.	Tuff, gray and greenish gray, with thin beds of hackly mudstone	47
31.	Mudstone, greenish gray, tuffaceous	16
30.	Tuff, gray white	47
29.	Sandstone, greenish gray	10
28.	Sandstone, olive green, tuffaceous, with few thin lenses of coarse-grained sandstone	40
27.	Sandstone, olive green, coarse grained	19
26.	Sandstone, greenish gray to olive green, tuffaceous	40
25.	Sandstone, dark olive green, coarse grained	9
24.	Sandstone, olive green, tuffaceous, extensively baked in basal 15 feet	76
	Sill, basalt, 34 feet thick.	
23.	Mudstone, gray and light olive green, tuffaceous, baked	15
22.	Sandstone, gray and light yellow, tuffaceous; olive-green, fine-grained, tuffaceous siltstone and mudstone	419
21.	Sandstone, gray, massive	50
20.	Sandstone, gray and light yellow, conglomeratic	31
19.	Sandstone, gray and olive green, fine grained, platy, with 5-foot bed of coarse-grained sandstone at top	233
18.	Sandstone, gray and light blue gray, tuffaceous	142
17.	Conglomerate, gray, coarse	8
16.	Clay, gray	10
15.	Sandstone, gray, medium grained	8
14.	Clay, greenish gray	9
13.	Sandstone, gray	6
12.	Clay, light greenish gray	10
11.	Sandstone, gray, medium grained	9
10.	Clay, gray	4
9.	Sandstone, gray, cross-bedded, upper 5 feet is conglomeratic with many limestone pebbles	15
8.	Sandstone, gray, fine grained, tuffaceous	140
7.	Sandstone and mudstone, tuffaceous	27
6.	Sandstone, coarse, cross-bedded, in 2-foot beds interbedded with 2-foot conglomerate beds containing cobbles of sedimentary rocks as much as 4 inches long that look like shingles	19
5.	Sandstone, gray, fine grained	8

	Thickness (Feet)
4. Clay, gray, interbedded with layers of gray sandstone	42
3. Sandstone, gray, conglomeratic, with limestone pebbles	10
2. Sandstone, gray white and yellowish brown, hard, coarse grained, 10 feet thick, with limestone pebbles at top. Underlain by gray, hard, vuggy siltstone	165
1. Sandstone, gray and olive gray, hard, conglomeratic, with limestone pebbles	33
Total	3,438

Unconformity(?).
Canoe(?) Formation.

Round Mountain.—The western facies of the Chisos Formation is well exposed west of Round Mountain (Pl. II; G, 12) (fig. 86). Here the Alamo Creek Basalt rests on an eroded surface in the Javelina Formation. It reaches its maximum thickness (208 feet) in this area and its upper surface is eroded. The Ash Spring Member is absent, the upper surface of the Bee Mountain Basalt is eroded, several lava units above the Bee Mountain Member, not recognized in some places, are present, the Tule Mountain Trachyandesite is abnormally thin, and tuff, sandstone, conglomerate, and lava units above the Tule Mountain Member, in some places, are absent. Nevertheless, it is the most complete section of the western facies of Chisos Formation.

Because of the map scale it was impossible to show all of the thin lava and tuff units that occur at some localities. Sections 37, 38, and 39 on Plate X include several thin tuff and lava units not shown on the geologic map (Pl. II).

Lithologic description and thicknesses of



Fig. 86. Looking eastward across Chisos Formation outcrops toward Round Mountain.

A, Round Mountain (Pl. II; G, 12). B, Line of measured section (Pl. X, no. 37). C, Alamo Creek Basalt. D, Tuff and tuffaceous clay and mudstone in Chisos Formation. E, Bee Mountain Basalt. F, Mule Ear Spring Tuff. G, Tule Mountain Trachyandesite. H, Wasp Spring Flow Breccia and undifferentiated lava. I, Burro Mesa Riebeckite Rhyolite.

units measured on the west side of Round Mountain follow (Pl. X, no. 37).

Section of the Chisos Formation (measured by planetable) exposed west of Round Mountain (Pl. X, no. 37).

		Thickness (Feet)
South Rim Formation.		
Angular unconformity.		
Chisos Formation—		
81.	Tule Mountain Trachyandesite Member—trachyandesite porphyry of uniform texture but probably consisting of three or more flows indicated by steplike benches in the escarpment. Weathers reddish brown and caps most of the ridge extending southeastward from Round Mountain	93
80.	Tuff, gray and grayish white, bedded, containing pebbles near top	40
79.	Tuff, gray white	55
78.	Basaltic lava	11
77.	Tuff, gray white, bedded	52
76.	Basaltic lava	4
75.	Mule Ear Spring Tuff Member—tuff, gray and pinkish gray, indurated, weathers brown	7
74.	Tuff, pink and gray	39
73.	Basaltic lava	10
72.	Tuff, pink and green	25
71.	Basaltic lava	11
70.	Sandstone, pink, tuffaceous	16
69.	Mudstone, green and greenish gray	10
68.	Mudstone, pink, tuffaceous	5
67.	Bee Mountain Basalt Member—consisting of three or more separate flows. Basalt, fine grained, dense; scoriaceous bands are prominent at flow contacts and many cavities are filled by secondary minerals	244
66.	Clay, gray, tuffaceous	4
65.	Sandstone, gray, tuffaceous, coarse grained	2
64.	Clay, gray, tuffaceous	8
63.	Sandstone, gray, coarse grained, tuffaceous, containing igneous pebbles 4 inches across	6
62.	Tuff and mudstone, gray, poorly bedded, mostly covered	115
61.	Mudstone, gray, tuffaceous	100
60.	Sandstone, gray, coarse grained, conglomeratic, cross-bedded, tuffaceous, containing igneous pebbles, cobbles, and boulders as much as 12 and 14 inches across at base	16
59.	Clay, gray	17
58.	Sandstone, gray, tuffaceous, and gray and brown conglomerate with igneous cobbles and boulders as much as 14 inches across at base	22
57.	Mudstone, red and red mottled, partly covered	57
56.	Clay, white, silty, tuffaceous	36
55.	Mudstone, gray white, silty, tuffaceous	10
54.	Sandstone, massive, white, tuffaceous	42
53.	Tuff, white	5
52.	Sandstone, white, bedded, tuffaceous	13
51.	Tuff, white	6
50.	Tuff, white, indurated, forming ledge	10
49.	Sandstone, gray, cross-bedded, tuffaceous, with pebble lenses	6
48.	Mudstone, reddish	4
47.	Mudstone and tuff, gray, tuffaceous	33
46.	Tuff, gray white, bedded	127
45.	Tuff, white, with two 1-foot ledges near top	48
44.	Mudstone, pink and gray, nodular, tuffaceous	36
43.	Sandstone, pink, silty, nodular, tuffaceous	11
42.	Mudstone, pinkish, tuffaceous	6
41.	Tuff, white	4
40.	Mudstone, pinkish, silty, tuffaceous	4
39.	Tuff, white and pink, bedded	15
38.	Tuff, pink and white	14
37.	Mudstone, gray, massive, tuffaceous	11
36.	Tuff and mudstone, pink and gray white, partly covered	58
35.	Tuff and tuffaceous mudstone, gray white, partly covered, with prominent white tuff bed at top	60
34.	Sandstone, red, platy	5
33.	Mudstone, red	15
32.	Sandstone, gray, tuffaceous	13
31.	Clay and mudstone, red	12
30.	Sandstone, gray white, tuffaceous, coarse grained, slightly pebbly	6
29.	Sandstone, soft, gray, platy, partly covered	8
28.	Tuff, gray, and sandstone, gray, platy, tuffaceous	28
27.	Clay, maroon	6
26.	Sandstone, gray white, platy, cross-bedded	7
25.	Clay, gray	13
24.	Mudstone, gray white, tuffaceous	27
23.	Tuff and mudstone, gray white, partly covered	115
22.	Mudstone, red	6
21.	Sandstone, gray white, tuffaceous	24
20.	Conglomerate, with igneous pebbles as much as 2 inches across	5
19.	Mudstone, reddish and maroon	89
18.	Conglomerate	12
17.	Sandstone, red	5
16.	Mudstone, red	22

		Thickness (Feet)
15.	Conglomerate	5
14.	Clay, maroon and gray	12
13.	Conglomerate, with pebbles as much as 2 inches across	3
12.	Clay, maroon and gray, containing turtle bone. The beds are comparable in lithology and stratigraphic position to an interval that yielded skull and partial skeleton of *Uintacyon* sp., tooth fragments, and turtle bone near Cerro Castellan	19
11.	Conglomerate lens	4
10.	Mudstone, red	4
9.	Conglomerate, with igneous rock pebbles as much as 2 inches across	6
8.	Mudstone, red	3
7.	Tuff, massive, white	11
6.	Clay, gray, tuffaceous	5
5.	Tuff, brown, indurated	2
4.	Tuff, gray white, with clay-ball conglomerate	8
3.	Tuff, brown, indurated	6
2.	Tuff, gray white, with unconformity at base	9
1.	Alamo Creek Basalt Member—basalt, hard, dense, fine grained	187–208
	Total	2,230–2,251

Angular unconformity.
Javelina Formation.

Cerro Castellan area.—On the western slopes of Cerro Castellan (Pl. II; G. 9–10), erosion stripped the upper Chisos Formation, and the Wasp Spring Member of the South Rim Formation was deposited at a level 124 feet above the top of the Bee Mountain Basalt (fig. 87).

The Alamo Creek Basalt Member rests on an irregular surface of the Javelina Formation. This member is 138 to 158 feet thick, but about three-fourths of a mile to the northwest, it is only 40 feet thick with irregular lower and upper surfaces. The basal bed, overlying the basalt,



FIG. 87. Cerro Castellan. Tuff and tuffaceous materials in Chisos Formation and flow breccia and lava in the South Rim Formation.

A, Bee Mountain Basalt. B, Stream channel fill in top of Bee Mountain Basalt. C, Wasp Spring Flow Breccia, basal member of South Rim Formation. D, Burro Mesa Riebeckite Rhyolite. E, Line of measured section (Pl. X, no. 36). F, Unconformity between the Chisos and South Rim Formations.

is conglomeratic and contains lava cobbles. Conglomerate and conglomeratic sandstone, interbedded with tuff and mudstone, make up the next 120 feet. Mammalian remains include skull and incomplete skeleton of *Uintacyon* sp. of Middle Eocene age which were collected from one of the mudstones. Turtle skeletal remains are numerous and found in beds that appear similar to bed no. 12 in the Round Mountain section. A lava at the top of this unit may be a southern extension of the Ash Spring Basalt.

The Bee Mountain Basalt Member is 486 to 527 feet thick, the maximum thickness in the Park. Its surface is irregular and trenched to a depth of 41 feet in places. The trench is filled with bouldery debris cemented together with tuffaceous matrix which extends upward to the base of the South Rim Formation. Both the Mule Ear Spring and Tule Mountain Members are eroded there.

Description and thickness of the lithologic units recognized at Cerro Castellan follow (Pl. X, no. 36).

Section of Chisos Formation (measured by planetable) in the western slope of Cerro Castellan (Pl. X, no. 36).

		Thickness (Feet)
South Rim Formation.		
Angular unconformity.		
Chisos Formation—		
23.	Tuff, gray, bouldery	21
22.	Tuff, gray white, pebbly	11
21.	Tuff, gray white	7
20.	Flow breccia—agglomerate, yellowish, with tuff matrix, containing fragments and boulders of a wide variety of sizes and shapes as much as 10 × 10 × 10 feet across	60
19.	Agglomerate, gray white, with tuffaceous matrix, containing dark-colored boulders as much as 30 inches across	24
18.	Flow breccia, gray, tuffaceous, whose matrix contains dark lava boulders as much as 10 feet across; forms channel deposit in top of Bee Mountain Basalt	1–35
17.	Bee Mountain Basalt Member—consists of several flows. Parts have coarse vesicular structure with a variety of shapes and sizes of cavity fillings, drusy cavities, and veins. Calcite is the common cavity-filling and vein mineral	486–527
16.	Mudstone, gray, yellowish gray, and pink, tuffaceous	240
15.	Tuff and tuffaceous mudstone, gray white	156
14.	Tuff, massive, indurated, white	36
13.	Tuff, gray	22
12.	Clay, gray, tuffaceous	18
11.	Tuff, gray	24
10.	Clay, gray, tuffaceous	24
9.	Tuff, gray	36
8.	Clay, red	9
7.	Conglomerate, red, cross-bedded, with bone fragments	14
6.	Clay, gray and red mottled	18
5.	Tuff, white, banded pink, yellow, and gray, and interbedded brick-red mudstone. Contains titanothere(?), rhinoceros tooth fragments, a skull and partial skeleton of *Uintacyon* sp., and turtle bones	22
4.	Clay, gray	12
3.	Sandstone, white, with reddish conglomerate lens, tuffaceous	11
2.	Tuff and clay, gray	45
1.	Alamo Creek Basalt Member—basalt, dense, hard	138–158
	Total	1,435–1,530
Angular unconformity.		
Javelina Formation.		

Tule Mountain.—The Chisos Formation on the northern slope of Tule Mountain (Pl. II; L, 10) differs from that found elsewhere in the Park (fig. 82). From the Javelina–Alamo Creek contact up through the Ash Spring Member, the tuff-lava sequence is much like that found in other places, but above the Ash Spring most of the sequence is composed of coarse clastic rock, the upper 940 feet of which is boulder conglomerate unlike the Chisos Formation conglomerates elsewhere. Most of the boulders are igneous, they look like the Bee Mountain Basalt, and many of them are as much as 4 to 5 feet in diameter. The Bee Mountain Basalt is absent and the Mule Ear Spring Tuff rests on the boulder conglomerate (Pl. X, no. 41).

The basal unit of the coarse clastic sequence at Tule Mountain includes two beds of brick-red conglomerate which also

occur about 1½ miles north of Tule Spring (Pl. II; L, 11). Here they occur at the base of a coarse clastic sequence, 400 to 500 feet thick, that separates the Ash Spring and Bee Mountain Members. Brick-red sandstone and conglomerate crop out below the Bee Mountain Basalt on the northwest slope of Goat Mountain (Pl. II; J, 12) where the Ash Spring Basalt Member is absent.

Beginning about 72 feet above the upper brick-red beds at Tule Mountain, the Chisos Formation consists of sandstone, conglomerate, and massive boulder conglomerate, about 500 feet of which is mostly covered by terrace gravel (Pl. X, no. 41). These rocks are similar to those exposed below the Bee Mountain Member north of Tule Spring and northwest of Goat Mountain. The upper 566 feet of the coarse clastic sequence consists of well-exposed boulders and blocks of dark scoriaceous lava; many are up to 4 or 5 feet across with minor quantities of limestone cobbles in a tuffaceous matrix. This part of the sequence (566 feet) is totally unlike the Chisos Formation conglomerates in other places.

The boulder beds are best exposed in the northern slope of Tule Mountain. They thin rapidly in all directions. Their relation to the underlying tuffaceous rocks is obscured by alluvium, and they are believed to be of local origin. These beds are probably a fanglomerate deposit that accumulated in a local basin or perhaps a canyon. The Bee Mountain Basalt was not recognized; many of the boulders are scoriaceous with secondary minerals like the Bee Mountain Basalt, which suggests that the Bee Mountain Member was a source for the boulders. The canyon cutting and fanglomerate accumulation preceded the deposition of the Mule Ear Spring Tuff which rests directly on the boulder conglomerate and is beneath the Tule Mountain Trachyandesite cap rock.

Detailed thickness of units and lithologic description of the rocks follow (Pl. X, no. 41).

Section of Chisos Formation (measured by planetable) on the northern side of Tule Mountain (Pl. X, no. 41).

		Thickness (Feet)
50.	Tule Mountain Trachyandesite Member—trachyandesite porphyry, hard, dense, reddish-brown groundmass and feldspar phenocrysts form cap rock on Tule Mountain	202
49.	Mule Ear Spring Tuff Member—tuff, pink and yellowish gray, indurated	10
48.	Boulder conglomerate, gray and brown, massive, mostly igneous pebbles, cobbles, and boulders, with sporadic limestone cobbles as much as 12 inches across forming the upper slope of Tule Mountain	387
47.	Sandstone, gray, forming lens in boulder conglomerate	6
46.	Boulder conglomerate, gray and light brown, massive, partly covered near base	49
45.	Sandstone, gray, pebbly, tuffaceous, forming lens in conglomerate	8
44.	Boulder conglomerate, gray and light brown, massive, with well-rounded igneous boulders as much as 2 and 3 feet across	68
43.	Sandstone, gray, pebbly, tuffaceous, forming lens	8
42.	Conglomerate, gray and light brown, massive, with rounded igneous boulders as much as 4 and 5 feet across	40
41.	Covered	135
40.	Boulder conglomerate, gray, massive	25
39.	Covered	117
38.	Boulder conglomerate, gray, massive, with well-rounded igneous boulders as much as 3 feet across	19
37.	Sandstone, gray, pebbly, tuffaceous	9
36.	Covered	44
35.	Conglomerate, dark brown, with gray-white, pebbly, tuffaceous sandstone matrix. Contains rounded boulders and scoriaceous lava blocks as much as 3 to 4 feet across	27
34.	Covered	141
33.	Conglomerate, gray and light brown, containing rounded scoriaceous lava boulders as much as 1 foot across	22
32.	Sandstone, gray, pebbly, tuffaceous, with lenses of gray tuffaceous mudstone	76
31.	Conglomerate, reddish, with igneous rock boulders as much as a foot across	5
30.	Sandstone, gray, tuffaceous	14
29.	Covered, probably underlain by tuff or mudstone	22

		Thickness (Feet)
28.	Mudstone, gray white, tuffaceous	11
27.	Sandstone, gray, conglomeratic, tuffaceous, with a few igneous cobbles	44
26.	Conglomerate, brick red. Upper 20 feet is sandy with small pebbles. In middle are lenses of boulders a foot in diameter. Basal 20 feet has lenses of variable thickness, containing igneous boulders 2 to 3 feet across	86
25.	Sandstone, gray, pebbly, tuffaceous	10
24.	Clay, gray	5
23.	Conglomerate, brick red. Sand and tuffaceous siltstone in top 20 feet and a few boulders as much as 12 inches across. Lower part is irregularly lenticular with some igneous boulders 2 feet across	45
22.	Sandstone, gray, pebbly, tuffaceous, with silt bands, containing irregular lenses of conglomerate, 2 feet or more thick. The conglomerate lenses contain igneous boulders as much as 1½ feet across	55
21.	Ash Spring Basalt Member—consists of two or more lava flows. The top 30 to 40 feet is vesicular to frothy. Amygdules are filled with chalcedony and calcite. The middle 20 feet is weathered soft and rotten; in the freshest exposures it is fine-grained, slightly porphyritic basalt containing some calcite veins and vesicle fillings. The basal 50 feet is fine grained, slightly porphyritic, and hard	115
20.	Siltstone and mudstone, gray white, tuffaceous	60
19.	Covered by terrace gravel	165
18.	Mudstone, gray white, tuffaceous	5
17.	Sandstone, gray white and pinkish, tuffaceous, coarse grained, slightly cross-bedded, containing pebbly layers	10
16.	Covered	14
15.	Sandstone, white, tuffaceous	2
14.	Mudstone, gray, white, and pink, tuffaceous	20
13.	Covered by terrace gravel	79
12.	Mudstone, pinkish gray, tuffaceous	6
11.	Sandstone, greenish and reddish brown, tuffaceous, pebbly, cross-bedded. Basal 5 feet is conglomeratic with smooth igneous pebbles ⅛ inch to 2½ inches across	15
10.	Mudstone, grayish white, tuffaceous	32
9.	Covered	51
8.	Mudstone, gray white, tuffaceous, bedded	20
7.	Covered by terrace gravels	50
6.	Mudstone, white, tuffaceous	12
5.	Clay, gray white	4
4.	Clay, pinkish gray, silty, tuffaceous	10
3.	Sandstone, gray, coarse grained, silty	7
2.	Clay, gray, silty	4
1.	Alamo Creek Basalt—fine, dense, hard	30
	Total	2,401

Angular unconformity.
Javelina Formation.

West side of Burro Mesa.—The youngest rocks in the Chisos Formation are exposed at Burro Mesa. The basal unit is the Alamo Creek Member which rests on an eroded surface in the Javelina Formation. The Ash Spring Basalt, the brick-red conglomerate, and about half of the conglomeratic sequence (exposed at Tule Mountain) are present. The Bee Mountain Member includes a tuffaceous clay unit. the Mule Ear Spring Tuff is absent in some places, and locally the Tule Mountain Trachyandesite rests directly on the Bee Mountain Basalt. Thickness of units and general lithologic description of the rocks for the upper part of the sequence are given in section no. 40, Plate X.

Casa Grande.—A partial Chisos Formation section is exposed in the western slope of Casa Grande (Pl. II; L, 16). The basal relations are not clear as the contact is extensively covered. The Alamo Creek Basalt is absent and the rocks representing a stratigraphic level above the Alamo Creek Member rest on the Canoe Formation (Pl. X, no. 43). The Ash Spring Basalt is the lowest named member that is exposed (fig. 88). The Bee Mountain Basalt is present, but the upper Chisos Formation beginning 44 feet above the Bee Mountain Member was eroded prior to deposition of the overlying South Rim Formation. Detailed thicknesses of the units and lithologic description of the rocks follow (Pl. X, no. 43).

Partial section of Chisos Formation (measured by planetable) on the northwest side of Casa Grande (Pl. X, no. 43).



FIG. 88. Casa Grande where a partial section of the Chisos volcanic sequence is exposed in the peak's northwestern face and slope.

A, Ash Spring Basalt. B, Line of measured section (Pl. X, no. 43). C, Tuffaceous sandstone in Chisos Formation. D, Bee Mountain Basalt. E, Base of South Rim Formation, a brown rhyolite porphyry. F, Wasp Spring Flow Breccia. Cap rock on Casa Grande, a fine-grained riebeckite rhyolite.

		Thickness (Feet)
South Rim Formation.		
Unconformity.		
Chisos Formation—		
35.	Sandstone, gray, medium grained, tuffaceous	40
34.	Bee Mountain Basalt Member— Basalt, upper flow, hard, fine to medium grained, erosion surface at top	42
	Basaltic flow breccia with inclusions of igneous rocks, mostly basalt, up to 4 inches across	4
	Basalt, hard, fine grained	7
33.	Sandstone, gray, medium grained, tuffaceous (a lens within the Bee Mountain Member)	13
32.	Basalt, basal flow, scoriaceous at base, remainder hard and medium grained	24
31.	Sandstone, gray, medium grained, tuffaceous	86
30.	Massive conglomerate, dark gray and light brown, with boulders up to 18 inches across, including Comanchean limestone, chert, novaculite, and lava	50
29.	Sandstone, buff to yellowish gray, tuffaceous, fine grained, with internal molds of a terrestrial gastropod akin to the genus *Helix*	25
28.	Sandstone, gray, coarse grained, mostly covered, but forms a ledge 200 yards northeast of line of section	55
27.	Sandstone, gray, medium grained, tuffaceous, thin bedded	30
26.	Mudstone, gray, tuffaceous	3
25.	Sandstone, gray, tuffaceous, pebbly	9
24.	Sandstone, gray, tuffaceous, well bedded	18
23.	Sandstone, gray, tuffaceous, massive, coarse grained, with conglomeratic lenses containing limestone and lava cobbles up to 4 to 6 inches across	21
22.	Sandstone, gray, tuffaceous, with lenses of pebbly sandstone	10
21.	Tuff and tuffaceous mudstone, gray, partly covered	15

		Thickness (Feet)
20.	Mudstone, gray, tuffaceous, with lenses of gray, tuffaceous sandstone	28
19.	Mudstone, gray, tuffaceous, with 4-foot lens of gray sandstone	11
18.	Mudstone, maroon and gray, tuffaceous	14
17.	Covered	11
16.	Sandstone, reddish, tuffaceous, irregular base	8
15.	Ash Spring Basalt Member—Basalt, hard, fine grained, scoriaceous with much secondary mineralization	65
14.	Tuff, indurated, gray white, contains gastropods of the genus "*Helix*"	3
13.	Mudstone, maroon	9
12.	Covered	32
11.	Mudstone, yellowish gray, tuffaceous	13
10.	Covered	34
9.	Sandstone, yellowish gray, tuffaceous, cross-bedded, igneous pebbles at base	8
8.	Mudstone, gray, yellowish gray, and maroon	87
	Dike, quartz porphyry, irregularly tabular, cross-cutting, 32 feet thick.	
7.	Clay, pink	5
6.	Covered	31
5.	Clay and mudstone, gray and maroon, mostly covered.	104
4.	Mudstone, reddish brown, cutting quartz porphyry dike 10 feet thick	33
3.	Covered	19
2.	Sandstone, gray, coarse grained, base covered	12
1.	Covered	20
	Total	999

Unconformity.
Canoe Formation.

FOSSILS AND AGE

The Chisos Formation has not been precisely dated. Mammal and turtle remains, fresh-water snails, and wood have been collected, but not all of the specimens are diagnostic. The eastern facies of the Chisos Formation overlies the Middle Eocene Hannold Hill Formation along the east side of the Chisos Mountains, which suggests an Upper Eocene age.

Mammalian remains were collected from a brownish mudstone bed, 27 to 33 feet thick, exposed in the banks of Blue Creek (Pl. II; G, 9) about a mile northwest of Cerro Castellan. They include a partial *Uintacyon* sp. skull and partial skeleton, several tooth fragments, a considerable quantity of turtle skeleton elements, and miscellaneous bone scrap. The assemblage is Late Eocene age.

Several tooth fragments and miscellaneous bone scrap were found in a pebbly tuffaceous deposit forming small knobs above the Alamo Creek Basalt on the southeastern corner of Black Mesa (Pl. II; J, 10). Similar tooth fragments and miscellaneous bone scrap were also collected from a tuffaceous gravel, within a 100-foot interval above the Alamo Creek Basalt in the lower southeastern slopes at Sierra Aguja (Pl. II; J, 6) and near Terlingua Abaja (Pl. II; J, 6). The bone material from Black Mesa, Sierra Aguja, and Terlingua Abaja is similar and was found in gravelly tuff or mudstone at about the same stratigraphic position above the Alamo Creek Basalt and is probably the same age.

At a locality in Mexico, about 4 miles south of Cerro Castellan, a leg bone and two tooth fragments were collected from a gravelly tuff about 100 feet below the Bee Mountain Basalt. Positive identification is impossible, but they are like titanothere(?) remains. The bone was found at a little higher stratigraphic level than the bones at Cerro Castellan, but the exact position could not be determined because the Alamo Creek Basalt is not exposed.

North of Blue Creek Canyon (Pl. II; K, 14), miscellaneous bone scraps were collected about 300 feet below the Bee Mountain Basalt in tuffaceous sandstone; these are higher in the section. Bone scraps were also collected from tuffaceous sandstone below the Ash Spring Basalt from along the eastern side of Burro Mesa (Pl. II; L, 14).

The assemblage of mammalian remains collected from the Chisos Formation in Big Bend National Park is not sufficient to date the beds precisely. Further collecting is necessary before the age can be determined. From the stratigraphic position

of the Chisos Formation, however, it is most likely that the basal units are Middle Eocene and the upper sequence, from the base of the Bee Mountain Basalt to top of the formation, is Upper Eocene.

Fresh-water gastropods were found in the Chisos Formation at several localities. These are most numerous at the northeastern end of Kit Mountain (Pl. II; J, 12), and the stratigraphic occurrences are indicated on Plate X, section 38. Several specimens were sent to J. B. Reeside, Jr., who (personal communication, March 12, 1965) identified them as an Eocene form of *Helix* sp. Similar fresh-water shells associated with turtle bones were collected from unit 12 at Round Mountain (Pl. X, no. 37).

Fresh-water snails were also collected from tuffaceous sandstone and gray-white tuff from the Chisos Formation on the western slope of Casa Grande (Pl. X, no. 43). United States Geological Survey staff members reported them to be akin to *Helix* and not known from beds older than Tertiary (letter from J. D. Sears, February 24, 1938).

Wood is present but not common in the Chisos Formation. Several blocks from tree trunks, 2 to 3 feet in diameter, and one stump crop out near the dike about 1¾ miles southwest of Oak Spring (Pl. II; L, 14); a silicified log, 18 inches in diameter, is exposed in Chisos beds about a mile northeast of Tortuga Mountain (Pl. II; J, 17). The wood is similar to that found in older Tertiary outcrops on Tornillo Flat.

The potassium-argon method for age determination was used for dating some of the lava members. The results are shown in table 9 (below).

All age determinations are of whole rock analyses, and the limits of the average ages refer to the range of possible analytical errors.

The anomalous age of the Bee Mountain Basalt is considerably younger than is compatible with its stratigraphic position, but the petrology of this lava suggests why it appears younger. The principal constituents of the analysed specimens were unaltered but most of the potassium was probably contained in a dark-green cryptocrystalline, formerly glassy groundmass representing the final alkalic magmatic fraction. Considerable argon leakage is known to take place in material of this kind, and leakage has probably taken place in the Bee Mountain Basalt to produce an abnormally young age.

South Rim (New) Formation

GENERAL FEATURES

The South Rim is the uppermost formation of the Big Bend Park Group (table 1) and is formed of thick lava and flow breccia bodies, conglomerate, sandstone, tuff, and tuffaceous mudstone. The formation is named from the South Rim of the Chisos Mountains (Pl. II; K, 16) where most of the lava–flow breccia units are prominent (fig. 89).

The base of the South Rim Formation is

TABLE 9. *Age determinations by the potassium-argon method.*

Unit	Millions of years
Tule Mountain Trachyandesite	28.4, 28.8 (Ave. 28.6 ± 1.5)[a]
Mule Ear Spring Tuff	30.8, 31.7, 32.1 (Ave. 31.5 ± 2.0)[a]
Bee Mountain Basalt	21.7, 23.5 (Ave. 22.6 ± 1.0)[a]
Ash Spring Basalt	32.4, 34.8 (Ave. 33.6 ± 1.5)[a]
Alamo Creek Basalt	40.1, 44.3 (Ave. 42.2 ± 2.0)[a]
Alamo Creek Basalt	38.7[b]
Alamo Creek Basalt	42.7[c]

[a] J. H. Halsey, Socony Mobil Oil Company, Dallas, Texas (personal communication, April 3, 1964).
[b] J. F. Evernden, University of California, Berkeley (personal communication, May 9, 1963).
[c] Data on plagioclase concentrate from G. H. Curtis, University of California, Berkeley.



Fig. 89. Type locality of the South Rim Formation.

A, Chisos Formation. B, Bee Mountain Basalt. C, Brown rhyolite. D, Wasp Spring Flow Breccia. E, Lost Mine Rhyolite. F, Burro Mesa Riebeckite Rhyolite, which truncates the lower members.

everywhere unconformable on older rocks and is in contact with rocks that range from the highest part of the Chisos Formation down to the Pen Formation. On the west side of Burro Mesa (Pl. II; L, 12), rocks in the middle South Rim sequence overlie the highest Chisos Formation, 408 feet above the top of the Tule Mountain Trachyandesite. Elsewhere on Burro Mesa, the same South Rim units are in contact with the Tule Mountain Trachyandesite itself. At many places the eroded upper surface of the Tule Mountain Trachyandesite Member is the top of the Chisos Formation (fig. 83). At Goat Mountain, the middle and upper South Rim Formation was deposited in a canyon that trenched the Chisos Formation to a level below the top of the Bee Mountain Basalt (fig. 90). A similar but wider channel is preserved at Kit Mountain (fig. 91), and farther southwest the upper South Rim Formation lies directly on the Javelina Formation.

The South Rim Formation is about 275 to 1,000 feet thick in the measured sections (Pl. X). At the South Rim and throughout most of the rest of the outcrop areas, the lava and flow breccia units vary in mineral composition, physical character, and thickness. Three of the units are sufficiently distinctive to justify formal names. In ascending order, these are (1) the Wasp Spring Flow Breccia Member, (2) Lost Mine Rhyolite Member, and (3) Burro Mesa Riebeckite Rhyolite Member. The basal flows are more varied in mineral content, lithology, and thickness than the formally named members and have been informally grouped under the term Brown rhyolite.

Field studies of the lava and flow breccia units were supplemented by laboratory examination of scores of thin sections, chemical analyses of a few, and paleomagnetism studies; the latter were by J. D. Martinez et al. (1960, pp. 38–39), then



Fig. 90. Cross section of canyon in southwestern side of Goat Mountain.

A, Tuff, sandstone, and conglomerate in Chisos Formation. B, Bee Mountain Basalt. C, Mule Ear Spring Tuff. D, Tule Mountain Trachyandesite. E, Wasp Spring Flow Breccia. F, Burro Mesa Riebeckite Rhyolite, top member of the South Rim Formation.

with the Humble Oil & Refining Company, in cooperation with the Bureau of Economic Geology. Age determinations of the top lava unit were made by S. S. Goldich, then at the University of Minnesota.

DESCRIPTION OF NAMED MEMBERS

Brown rhyolite member (new).—The term Brown rhyolite member is applied informally to a sequence of lava units at the bottom of the South Rim Formation. The rocks are exposed only in the area of the highest Chisos Mountains peaks, are probably of local origin, and range from less than 10 to 800 feet thick. The lavas range in composition from a dark plagioclase-rich rock with glassy base to a light felsite. Some beds are porphyritic, some have flow structures, and others contain inclusions.

Wasp Spring Flow Breccia Member (new).—The Wasp Spring Member is predominantly a flow breccia unit (fig. 92); at most places it is the base of the South Rim Formation. It is about 100 to 350 feet thick in the high Chisos Mountains area; normally it thins rapidly away from the highest Chisos Mountains peaks and is commonly less than 30 feet thick in the peripheral areas of the present outcrop. In addition to flow breccia units, the member also contains rhyolitic lava, coarse massive conglomerate, coarse sandstone, and tuff. The source of the Wasp Spring Member was probably in the central Chisos Mountains (location of vent not known) and as the extrusive activity progressed the material moved outward over the eroded surface on top of the Chisos Formation. A post-Chisos Formation canyon at Goat Mountain (fig. 90) and a valley extending farther toward the southwest (pp. 150–151) provided a channel for



FIG. 91. Looking northeast at Kit Mountain. The South Rim Formation occurs in a valley in Chisos beds.

A, Approximate line of measured section (Pl. X, no. 38). B. Bee Mountain Basalt. C, Mule Ear Spring Tuff. D, Tule Mountain Trachyandesite. E, Wasp Spring Flow Breccia. F, Burro Mesa Riebeckite Rhyolite.

the lava–flow breccia units to areas away from the source.

At some places in the Chisos Mountains the Wasp Spring Member is dominantly rhyolitic lava with conspicuous flow structures, sporadic inclusions, and only minor amounts of tuff. In general, the amount of lava decreases and the flow breccia increases away from the mountains. At places farthest from the mountains and especially east and northeast of Cerro Castellan (Pl. II; G, 10), much of the member is yellow, punky, tuffaceous flow breccia with boulders as much as 5 feet across interbedded with yellowish, tuffaceous, pebbly mudstone, gray tuffaceous sandstone, and some conglomerate with tuffaceous matrix.

Martinez et al. (1960, pp. 38–39) collected eight samples from four localities of the Wasp Spring Flow Breccia for paleomagnetism studies. The results showed some scatter of points when plotted on the Schmidt net. Scatter might be expected, because in a flow breccia some differential movement undoubtedly took place in the more fluid material at temperatures below the average Curie point temperature for the entire mass. Nevertheless, the Wasp Spring Member is fairly consistently magnetized in the direction of the earth's present field, lending support to the field conclusions that the Wasp Spring Member is a part of the South Rim Formation extrusive sequence.

Lost Mine Rhyolite Member (new).— The Lost Mine Rhyolite Member is named from Lost Mine Peak (fig. 93) whose top is capped by the lava that also occurs on Crown Mountain, the high mesa between the South Rim and Emory Peak, and on an unnamed peak about 2 miles southwest of Emory Peak. The Lost Mine Member overlies the Wasp Spring Flow Breccia and



FIG. 92. Wasp Spring Flow Breccia. The tuffaceous matrix contains boulders up to 2 feet across.

is preserved only in the higher Chisos Mountains. It is mostly a reddish rhyolite porphyry but parts are nonporphyritic, and some are glassy and have complex flow banding. The present outcrop pattern, thickness of the flow units, complexity of the flow structures, and distribution of the rocks suggest that the source was in the central Chisos Mountains but the vent has not been found. Paleomagnetism studies show that the lava is magnetized in the direction of the earth's present field (Martinez et al., 1960, pp. 38–39).

Burro Mesa Riebeckite Rhyolite Member (new).—The Burro Mesa Riebeckite Rhyolite is named from Burro Mesa (Pl. II; L, 12) where the member is the flow forming the highest peak on the western rim. It also forms the cap rock on Emory Peak (fig. 98) and is on several peaks and ridges southwest of the Chisos Mountains. It is a highly siliceous, medium-grained, gray rhyolite with quartz phenocrysts in a riebeckite matrix. The base is finely crystalline to glassy; flow structure is most evident in the basal 50 feet where platy riebeckite crystals form bands parallel to the flow structure.

The Burro Mesa Riebeckite Rhyolite is the youngest member of the South Rim Formation. It truncates the Lost Mine and younger members southeast of Emory Peak (fig. 89) but in most areas outside the highest Chisos Mountains, it lies directly upon the Wasp Spring Member (fig. 94). The lava unit is 400 to 500 feet thick at the type locality on Burro Mesa and has a similar thickness on Emory Peak and several peaks and ridges southwest of the Chisos Mountains.

The lava of the Burro Mesa Riebeckite Rhyolite Member probably came from several vents, but the vent or vents have not been located. The intrusions at Ward Mountain (Pl. II; K–L, 15), Pulliam Peak (Pl. II; M, 15–17), and Tortuga Mountain (Pl. II; H–J, 17) and several dikes, especially the Hayes Ridge dike (Pl. II; K, 16–19), are riebeckite microgranite similar chemically and lithologically to the



Fig. 93. South Rim Formation in the northern slope of Lost Mine Peak.

A, Brown rhyolite porphyry. B, Wasp Spring Flow Breccia, with small cave ("Watchman's House") near base. C, Lost Mine Rhyolite. D, Approximate contact between extrusive units and the Pulliam Peak intrusion.

extrusive rocks. Most of the large intrusions in the Chisos Mountains are probably from the same magma and are of the same age. The Hayes Ridge dike cuts the Wasp Spring Member near Boot Canyon (Pl. II; K, 16) and has been traced to within half a mile of the Burro Mesa Riebeckite Rhyolite near Emory Peak (fig. 95). The Ward Mountain intrusion, which is petrographically and chemically the same rock as the Hayes Ridge dike, deformed the entire South Rim Formation toward the southeast and is younger (fig. 89). The major riebeckite-bearing intrusive masses now exposed in the Chisos Mountains probably came from the same magma source as the extrusive rock in most of the South Rim Formation, but the vent or vents from which the extrusive rocks were erupted were obliterated by erosion or by the younger intrusions.

Several spinelike intrusions and small dikes in the southwestern part of the Park are riebeckite rhyolite and although fine grained, they are mineralogically and chemically like the Burro Mesa Riebeckite Rhyolite extrusion. Some of the spines are probably vents and include the so-called "petrified tree" about three-tenths of a mile northwest of Cerro Castellan (fig. 96); four less spectacular spines and two dikes occur nearby. A cluster of four spines and two dikes lies in the Javelina Formation six-tenths of a mile west of Trap Mountain (Pl. II; H, 11); a mile farther north, seven small spines are clustered in the basal Chisos Formation and two slightly larger ones occur half a mile northwest of Trap Mountain. Farther southwest are three spines and six dikes in an elongate belt, mostly in the Javelina Formation. Similar spines and small dikes occur 1¼ miles northeast of Mule Ear Spring and a mile east of the spring. Some and possibly all of these spines and dikes were feeders for the Burro Mesa Riebeckite



FIG. 94. Contact between the Wasp Spring and Burro Mesa Members on the west side of Burro Mesa. Similar contact relationships were observed west and southwest of the Chisos Mountains. A, Wasp Spring Flow Breccia. B, Burro Mesa Riebeckite Rhyolite.

Rhyolite flow in the southwestern part of the Chisos Mountains, but they are not of sufficient size or location to have supplied all the accumulation, and especially the thick masses on Emory Peak and Burro Mesa.

Martinez et al. (1960, pp. 38–39) collected samples of the Burro Mesa Member from five localities for paleomagnetism studies. The results showed that the Burro Mesa Riebeckite Rhyolite Member is consistently magnetized in the direction of the earth's present field.

LOCAL FEATURES

South Rim area.—The lowest lava in the South Rim Formation, at the base of the South Rim escarpment, is a greenish-brown, fine-grained, plagioclase-rich rock, with a glassy base, that from a distance looks like basalt. It is the bottom flow of the brown rhyolite unit, is about 50 feet thick, and flowed into depressions on an irregular surface of the Chisos Formation at a level about 100 feet above the Bee Mountain Basalt Member (Pl. X, no. 44).

The Wasp Spring Member, with irregular base, lies directly on the brown rhyolite flow mentioned above. The member is 250 feet thick and consists of several flows. The basal 15 feet is a pitchstone with thin bands of glassy rhyolite. The predominant rock is pinkish rhyolitic flow breccia with sporadic inclusions. The top 20 feet is a hard, pinkish, rhyolitic tuff with inclusions and contains a conglomeratic layer 2 feet below the top.

The Lost Mine Member forms the high mesa between the South Rim and Emory Peak where it consists of four flows between the Wasp Spring and Burro Mesa Members (fig. 89). Individual flows are thick and massive, forming the vertical part of the South Rim escarpment (fig. 97). Most flows are porphyritic, some are conspicuously porphyritic, and a few are



FIG. 95. Hayes Ridge dike, along the southern bank of Boot Canyon where it cuts the Wasp Spring Flow Breccia and Lost Mine Rhyolite.

A, Hayes Ridge dike. B, Chisos Formation. C, Wasp Spring Flow Breccia. D, Lost Mine Rhyolite. E, Burro Mesa Riebeckite in Emory Peak.

nonporphyritic or glassy. They are brown, light brick red, yellow, and gray; each varies in thickness and physical character, and they seem to interfinger along their margins.

In the face of the South Rim escarpment, the lowest flow is 92 feet thick and is a gray, fine-grained, massive lava with a few alkali feldspar phenocrysts up to 1/8 inch long. It has some riebeckite but is poor in quartz. The second unit is a yellowish-gray, indurated tuff bed 2 feet thick. Above the tuff is 50 feet of massive, fine-grained, greenish rhyolite. It contains visible quartz and more riebeckite than the basal flow. The fourth unit, also 50 feet thick, is massive but not as hard as either the underlying or overlying lavas. It has irregular base and top, is a greenish-gray, fine-grained riebeckite rhyolite, and very poor in visible quartz. The top lava is 100 feet thick with irregular base and top (fig. 97). It is pink to yellow rhyolitic flow breccia and yellowish tuffaceous flow breccia with yellowish-gray glassy bands interbedded with light brick-red rhyolitic feldspar porphyry. The number of phenocrysts varies from layer to layer; in some places they are about 30 percent of the total rock and are as much as four-tenths of an inch long.

The top of the Lost Mine Member was beveled by erosion prior to deposition of the Burro Mesa Riebeckite Rhyolite flows (fig. 89). The Burro Mesa Member is 400 feet thick in Emory Peak. The contact around the base of Emory Peak is mostly covered, but in one arroyo, on the southwestern side of the peak, the Burro Mesa—Lost Mine contact is exposed. Here the basal 15 feet of the Burro Mesa Member is a black pitchstone with irregular light-gray, partially devitrified areas. The next 100 feet contains inclusions of the Lost

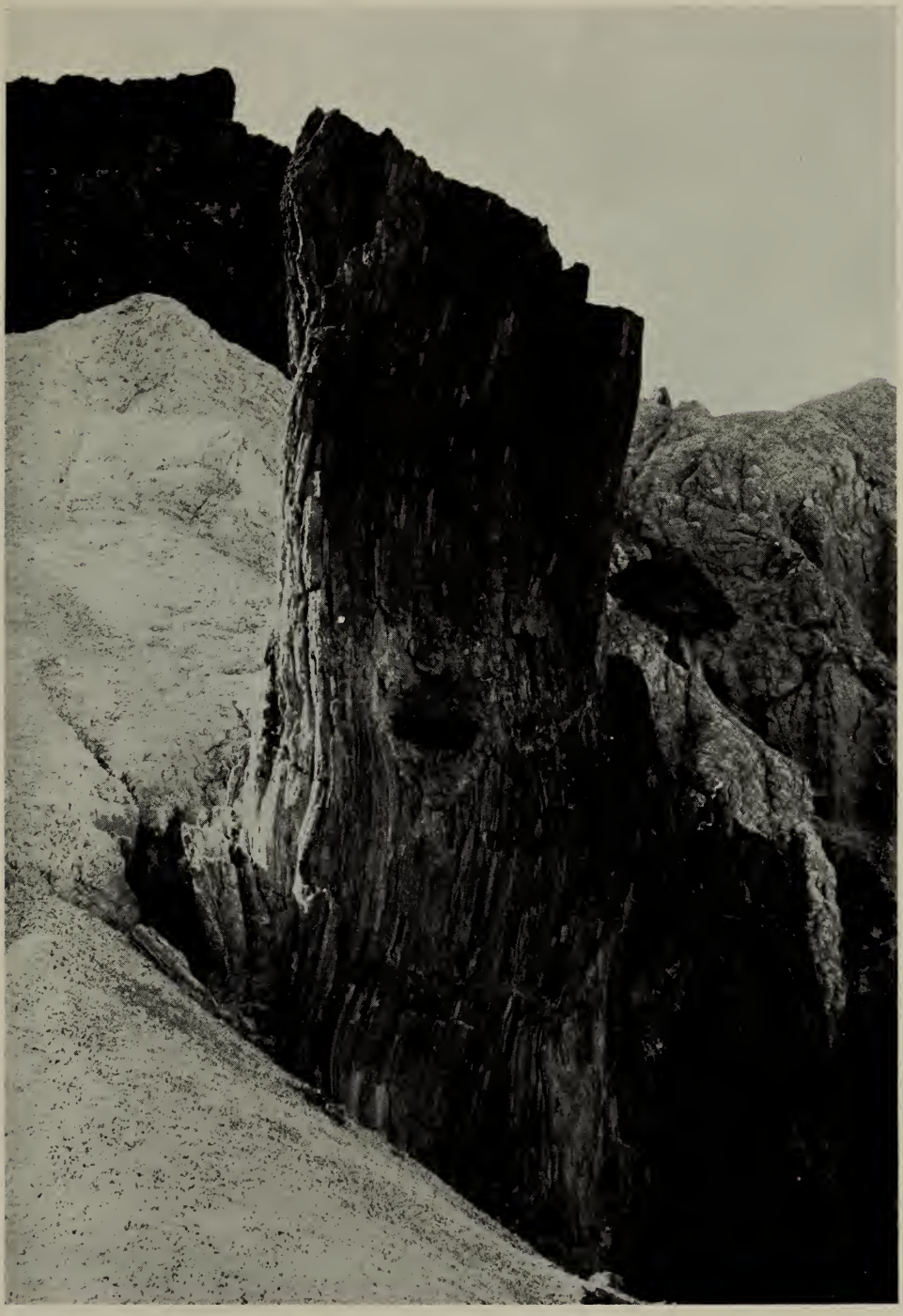


FIG. 96. A small intrusion of glassy riebeckite rhyolite about 20 feet high is three-tenths of a mile northwest of Cerro Castellan. Because of the concentric flow structure, this mass has been frequently misinterpreted as a fossil tree. The "knot hole" at one time probably held an inclusion.



FIG. 97. Massive Lost Mine Rhyolite which forms the crest of the South Rim. At least four major flows separate the Wasp Spring in the lower part of the South Rim from the Burro Mesa Riebeckite Rhyolite in Emory Peak (A).

Mine Member and other lava blocks up to 2 feet in diameter. The remainder of the Burro Mesa Member is a paisanitic riebeckite microgranite. It is highly siliceous, comparatively low in alumina, and contains sodic amphiboles, pyroxenes, considerable riebeckite, and alkali feldspar. The Burro Mesa Riebeckite Rhyolite rock exposed in Emory Peak is mostly medium to coarse grained and was first believed to be an intrusion, but recent studies show that it is a thick flow with glassy base that truncates older lava members in the South Rim Formation.

Basin area.—Rocks of the South Rim Formation are well exposed at Casa Grande (fig. 88) and in the north side of Emory Peak (fig. 98). In the west face of Casa Grande the lowest South Rim lava unit is a brown and greenish rhyolite porphyry with prominent flow structure in some layers. The lava is 110 feet thick and rests on Chisos Formation about 40 feet above the Bee Mountain Member (Pl. X, no. 43). The basal 15 feet is a brown flow breccia with inclusions, mostly lava, up to 18 inches across. Above is glassy rhyolite that grades upward into rhyolite porphyry. The phenocrysts are not more than $\frac{1}{8}$ inch long.

Above the Brown rhyolite unit is the irregular base of the Wasp Spring Flow Breccia Member. Here it is mostly reddish-brown rhyolite with flow structures and orange rhyolitic flow breccia. Some of the lower layers contain inclusions up to 6 inches across. The member is 150 feet thick and terminates upward at the base of the cap rock (fig. 88).

The Lost Mine Member forms most of the cap rock on Casa Grande, but individual flows are not as easily distinguished as in the face of the South Rim escarpment. Most of the rock is greenish-gray and pink rhyolite that weathers light brown. Some layers are glassy and others are porphyritic



FIG. 98. Looking south across the Basin of the Chisos Mountains.

A, Ridge of tuffaceous Wasp Spring Flow Breccia resting upon Aguja Sandstone. B, Rhyolite with inclusions comprising the upper Wasp Spring. C, Burro Mesa Riebeckite Rhyolite in Emory Peak. D, The "Water Tower," a rock column west of Emory Peak, made of rhyolitic flow breccia.

with feldspar phenocrysts up to 1/8 inch long. Most thin sections show some riebeckite, but riebeckite and quartz are not readily distinguished in hand specimen. Part of the upper cap rock, up to about 100 feet in one open joint, is a fine-grained riebeckite rhyolite and probably the base of the Burro Mesa Member.

The base of the South Rim Formation in the south side of the Basin is the Wasp Spring Member. Here the basal unit is a massive tuffaceous flow breccia with boulders up to 5 feet in diameter. It rests on the Pen and middle Aguja Formations along the South Rim trail. In the slope extending southward toward Emory and Toll Peaks, the tuffaceous flow breccia grades upward into a rhyolitic lava with inclusions as much as 2 feet in diameter (fig. 98). This lava forms the columns at the foot of Toll Peak, the so-called "water tower" (a rock column west of Emory Peak), and the "cowboy's boot" (fig. 99). The top of Emory Peak is formed of the Burro Mesa Member; in the northern slope of the peak, the Burro Mesa Riebeckite Rhyolite flows transgress the Lost Mine Member and lie directly on the Wasp Spring Flow Breccia.

Pummel Peak—Lost Mine Peak area.— The character of the extrusive material, structural features, and thickness of rocks suggest that the source from which the lower South Rim members came was a vent in the Lost Mine—Pummel Peak area. On the east side of Pummel Peak the basal lava is a brown rhyolite with small sporadic inclusions and complex flow structure (fig. 100). It rests on the Chisos Formation 40 feet above the Bee Mountain Basalt Member and is 100 feet thick (Pl. IX, no. 45). The Brown rhyolite is mostly a massive lava with some layers of feldspar prophyry and has small sporadic inclusions near the base. On the west side of Pummel Peak,



FIG. 99. The "cowboy's boot," a column of Wasp Spring Flow Breccia in the side of Boot Canyon about a mile northeast of Emory Peak. (Photograph by Hunter's of Alpine, Texas.)



FIG. 100. Wasp Spring Flow Breccia, chiefly banded rhyolite, in the southeastern face of Pummel Peak.

A, Brown rhyolite, base of the South Rim Formation (Pl. X, no. 45). B, Wasp Spring Flow Breccia. C, Lost Mine Rhyolite. D, Small intrusion.

about 1½ miles west of the area photographed in figure 100, the Brown rhyolite member is 300 feet thick. The base rests on Chisos Formation 500 feet below the Bee Mountain Basalt Member. The basal unit is a brown and greenish-brown rhyolite about 150 feet thick. Some layers are porphyritic but all have inclusions, some of which are as much as 30 inches in diameter. Flow structure is prominent and the dips are toward the west. The topmost 100 feet of the member is a light-gray to white felsite.

About a mile farther west, in the southeast slope of Lost Mine Peak, the base of the South Rim Formation is not exposed. The lowest exposed lava is a light-gray felsite (about 100 feet exposed) that weathers yellowish white. This lava can be traced northward to the pass at Smugglers Gap west of Panther Peak (Pl. I). The light felsite is overlain by 700 feet of Brown rhyolite in the southeast flank of Lost Mine Peak. The Brown rhyolite is nonporphyritic and all of it contains inclusions; its flow bands dip as much as 45° in random directions. On the northwest side of Lost Mine Peak the Brown rhyolite rests on Chisos Formation below the Bee Mountain Member. The lava is mostly massive, flow structure is not prominent, there are few inclusions, and the light felsite facies is absent. At least the upper part of the unit was deformed by the Pulliam Peak intrusion.

The Wasp Spring Flow Breccia Member lies on and truncates the different lavas in the Brown rhyolite. On the east side of Pummel Peak the Wasp Spring Member is 300 feet thick. It is dominantly a rhyolitic lava with conspicuous flow structure that dips in random directions but mostly west at angles up to 40° (fig. 101). The rock is dominantly bands of yellowish rhyolitic flow breccia alternating with bands of yellowish-brown, brown, greenish, and black glassy rhyolite. In Lost Mine



Fig. 101. Dipping flow bands in rhyolite in the Wasp Spring Member, eastern side of Pummel Peak.

Peak and Crown Mountain, most of the rock is red, brown, greenish-black, glassy rhyolite lava. Some beds are Brown rhyolite and in some places there are small phenocrysts.

There is 100 feet of Lost Mine Peak lava on the highest parts of Pummel Peak, about 30 to 50 feet in the cap rock on George Wright and Panther Peaks, an estimated 200 feet on Crown Mountain, and 227 feet on Lost Mine Peak. The rock is predominantly brownish rhyolite, most of it is porphyritic, and the phenocrysts are usually less than ¼ inch long. Examination of thin sections shows that the phenocrysts are mostly alkali feldspar; some quartz is present in all sections but is poor in some of them. Riebeckite is sporadic in most of the rocks but is a substantial rock constituent in one area on the west side of Lost Mine Peak.

The Burro Mesa Riebeckite Rhyolite Member occurs above an erosion surface at one locality on the western slope of Lost Mine Peak. This relatively small mass is cut by a dike that is riebeckite bearing and may have been a vent for local riebeckite rhyolite flows.

South Rim Formation outcrops outside the central Chisos Mountains.—Outside the central Chisos Mountains there are a variety of rock units in the South Rim Formation not typical of any member, but for the most part all of the rocks can be grouped into either the Wasp Spring Flow Breccia or Burro Mesa Riebeckite Rhyolite Members. On the west side of Burro Mesa the basal part of the Wasp Spring Member is a massive, tuffaceous conglomerate. This grades upward into the typical tuffaceous flow breccia (fig. 92). Locally, above the lowest flow breccia is a second conglomerate, several rhyolitic lavas, and one basalt, and more tuffaceous flow breccia to the top of the member. There is usually an erosion surface between the top of the Wasp Spring Member and the overlying Burro Mesa Riebeckite Rhyolite (fig.

94). At one place there is about 60 feet of basaltic lava between the two members.

The Burro Mesa Member is normally a highly siliceous, medium-grained, gray rhyolite, with quartz phenocrysts in a riebeckitic matrix. Most of the lava is uniformly massive and there is little evidence of more than one flow even in some of the thickest bodies. There is some flow structure in the basal part of the unit, and the flow structure may dip locally parallel to the topography, as in the canyon at Goat Mountain (p. 139). Normally the Burro Mesa forms an escarpment or dome-shaped cap at the top of the peak; this characteristic does not seem to vary whether the riebeckite-bearing rock is 50 or 500 feet thick. In the platy basal flows at Trap Mountain, the riebeckite crystals are elongated parallel with the plates and some of them are more than half an inch long. At Round Mountain, the Wasp Spring Member is the typical orange flow breccia unit with irregular base and top. Above it is 110 feet of dove-gray to buff rhyolite porphyry that is of local origin. This is overlain by the Burro Mesa Member that is fine grained and has contorted flow structure at its base.

The Wasp Spring and Burro Mesa Members form the cap rock on many of the peaks and ridges south and southwest of the central Chisos Mountains. The principal difference in the rocks is that with increasing distance from the central Chisos Mountains, the Wasp Spring has less lava, more flow breccia, and the matrix of the flow breccia is more tuffy. The Burro Mesa is finer grained, more platy, and there is a conspicuous increase in the zoned riebeckite growths along the plates.

FOSSILS AND AGE

The South Rim Formation has not been precisely dated. It lies over the Chisos Formation which is probably Upper Eocene or Oligocene (Duchesnean) age. Fossils have not been found. A potassium-argon age determination of the Burro Mesa Member made at the University of Minnesota by S. S. Goldich (personal communication, July 9, 1959) indicated approximately 30 million years. J. H. Halsey, Socony Mobil Oil Company (personal communication, April 3, 1964) obtained an average age of 29.4 million years from the analysis of two samples; this suggests an Oligocene age for the entire extrusive sequence and perhaps Late Oligocene for the Burro Mesa Member.

SURFICIAL DEPOSITS

GENERAL FEATURES

About a fourth of the surface of Big Bend National Park is covered by alluvial and colluvial deposits (Pl. II). They are terrestrial accumulations that vary widely from place to place in thickness, degree of consolidation, and kind of material. The deposits include (1) consolidated basin fill, (2) consolidated high terrace gravels, (3) alluvial fans and outwash gravel aprons covering slopes, (4) alluvium along stream valleys, and (5) talus. These materials were not studied in detail by the authors but are loosely divided into two groups according to age: (1) the older gravels of Miocene to Pleistocene age, which include the basin fill and consolidated high gravel terraces, and (2) alluvium of Pleistocene? to Recent age, which includes alluvial fans, outwash gravel aprons covering slopes, stream bed deposits, and talus.

Older Gravels and Silts

Cerro Castellan area.—Valley fill deposits of silt, sandy silt, and conglomerate crop out in most of the fault block valleys southwest of the Chisos Mountains (Pl. II). In some places these rocks have been tilted and may have been faulted; at least they occupy valleys between faults that have broken rocks as young as the Burro



Fig. 102. Valley fill northeast of Cerro Castellan includes silt and massive indurated conglomerate. The Burro Mesa Member caps a fault block ridge at upper right.

Mesa Riebeckite Rhyolite Member (fig. 102). In the fault block valley immediately southeast of Cerro Castellan and east of the ridge that extends southward from that peak, a silt and silty clay deposit has yielded several mammal skulls and lower jaws (Pl. II; F, 11–12, Locs. T11–T13). The deposits containing them are Early Miocene age.

Valley fill deposits in other areas.—Other fault block valleys southwest of the Chisos Mountains contain terrestrial deposits up to 100 feet thick. They are mostly conglomerate, consisting largely of lava cobbles. Some of the conglomerates contain silt lenses, and fragmental mammal bones have been found in a few of them. These were unidentifiable and their age is not known.,

A large area of the Solis Graben is floored by a hard conglomerate (20 to 30 feet thick) consisting mostly of Comanchean limestone cobbles. At one place, near the Rio Grande, the conglomerate may have been faulted (Pl. II; D, 22). Fossils have not been found and the age of the deposit is not known.

The fault block valleys in the Sierra del Carmen (Pl. II) are floored by consolidated gravel and silt deposits as much as 100 feet thick. In some of the valleys, the alluvium lies against fault scarps of massive Comanchean limestone; in others, the escarpments have receded and the terrestrial deposits cover the fault traces and abut against a fault line scarp. The cobbles are largely Comanchean limestone, but there are some chalcedony and igneous rocks. The silts are thin and for the most part form bands in the conglomerate. Fossils have not been found and the age of the deposit is not known.

High terrace gravels, Tornillo Creek valley.—East of the Chisos Mountains, chiefly along the west side of the Tornillo Creek valley, is a conspicuous deposit as much as 300 feet thick that extends from the southeast flank of the Grapevine Hills southeastward to beyond the Rio Grande (Pl. II; J–P, 20–24). Although the deposit

does not form a continuous blanket from the Grapevine Hills to the Rio Grande, isolated outcrops occur in the Rio Grande valley and there are extensive deposits in Mexico west of the Sierra del Carmen. The cap rock is consolidated conglomerate that includes cobbles and small boulders of nearly every igneous rock that crops out in the Chisos Mountains, as well as a few cobbles of Comanchean limestone and some black chert (fig. 103). Beneath the cap rock of indurated gravel are beds of silty clay and sandstone (fig. 104). This deposit was termed the Dugout Clays by Udden (1907a, p. 68). The basal part of the deposit is fine silt with thin sandstone beds that are light yellow, orange brown, or light greenish gray. Most of the sandstone contains gypsum or selenite as films along bedding planes and joints or as crystals in small cavities. Where the silt deposits are near the mountains they are interbedded with conglomerate or talus breccia. In Mexico, about 2 miles south of the head of Boquillas Canyon, fine silts lie against a high escarpment of Comanchean limestone. In a small isolated outcrop, believed to be part of this larger deposit, the senior author found elephant teeth (Pl. II; Q, 19; fig. 105) in a caliche-silt deposit.

High terrace gravels, Burro Mesa.—On Burro Mesa, gravel as much as 50 feet thick overlaps the South Rim Formation and some units in the Chisos Formation. The terrestrial accumulation was deposited on the downthrown side of the Burro Mesa fault and is mostly cobbles from the Chisos Mountains, but there are also some Comanchean limestone and black chert pebbles. There is some silt, mainly as lenses in the conglomerate, and fossils have not been found.

Alluvium

Gravel and silt of Pleistocene? and Recent age mantle the older terrestrial deposits, the pediment slopes that truncate the older formations adjacent to the high-



Fig. 103. Massive gravel deposits in the walls of Estufa Canyon east of the Chisos Mountains (Pl. II; M–N, 21–22).



FIG. 104. Typical silt deposit in the Tornillo Creek valley east of the Chisos Mountains.



FIG. 105. Elephant teeth in a caliche-silt deposit near Grapevine Spring.

lands, and the master stream valleys. Stepped slopes covered by alluvium occur south of the Chisos Mountains near the Rio Grande, west of the Chisos Mountains near Terlingua Creek, north of the Chisos Mountains near upper Tornillo Creek, and east and southeast of the Chisos Mountains along the tributary drainage to Tornillo Creek (Pl. II). Most of this youngest gravel and silt was laid down by sheetflood on the terraced surfaces. The base of the deposit is normally or commonly parallel to the truncated surface of the pediment slope, but where arroyos have dissected the pediments, the base of the alluvium is unconformable on the older deposits. Alternating periods of alluviation and trenching have resulted in complex cut-and-fill relations.

The alluvial gravels include a variety of rocks, most of which crop out in the adjacent highlands. Alluvial gravel surrounding the Chisos Mountains is formed chiefly of igneous rocks found in those peaks. There are also a few limestone and chert pebbles that probably were reworked from conglomerate in the Chisos Formation rather than from a distant source. In the Sierra del Carmen and on Mesa de Anguila, most of the alluvium was derived from the massive Comanchean limestone. Alluvium along the Rio Grande and other streams that head outside the Park includes rocks exposed along their respective drainage basins.

The water-laid alluvium consists of poorly sorted materials that vary from clay and silt to boulders a foot in diameter (fig. 106). The gravel is interbedded with irregular lenses and pods of silt, and the silt along the major streams indicates alternating periods of deposition and trenching. Along the Rio Grande and on Tornillo Flat, the wind has reworked the silt and fine-grained sand to form small dunes. The talus deposits are mostly coarse and contain angular blocks as much as 20 feet in diameter. The talus rests on Creta-



Fig. 106. Alluvium surrounding the Chisos Mountains.

ceous or Tertiary bedrock or on the older gravel.

FOSSILS AND AGE

Most of the surficial deposits have not been precisely dated. Some of the silt that accumulated in a fault block valley southeast of Cerro Castellan has yielded mammalian remains that have been tentatively identified as *Archaeolagus* sp., *Stenomylus* cf. *S. crassipes*, *Oxydactylus* cf. *O. gibbi*, *Nanotragulus* sp., and *Hypsiops* sp. cf. *H. luskensis*. These are Early Miocene age. The faults that formed the intermontane valley in which the mammal-bearing silt beds were deposited are post-Burro Mesa Member. Other fault block valley deposits may be the same age, but it is likely that the accumulation of the terrestrial debris was more or less continuous from the Miocene to Recent.

A correlation between the valley fill and high terrace deposits has not been established. Part of the high terrace deposits and especially those at Burro Mesa could be the same age for they are also on the downthrown sides of faults that cut the Burro Mesa Member. The high terrace deposits east of the Chisos Mountains have yielded only elephant teeth, which suggests Pleistocene age. The teeth came from a small isolated outcrop, probably correlative with the upper part of the larger deposit.

The alluvium is mostly Recent but some of it, especially deposits along the Rio Grande valley, is probably Pleistocene or older.

EARLY TERTIARY MAMMALS

John A. Wilson[6]

Introduction

During the summer of 1950 while conducting a University of Texas field geology course in and near the Big Bend National Park, the writer and members of the class discovered bones of Eocene mammals in what were thought to be Late Cretaceous beds. In order to determine the extent of the mammal-producing rocks, a return visit was made by a reconnaissance party composed of the writer, the late J. T. Lonsdale, former Director of the University's Bureau of Economic Geology, R. A. Maxwell, then Superintendent of Big Bend National Park, and J. H. Quinn. This return visit revealed the presence of Paleocene deposits, and the preliminary results were so satisfactory that a collecting permit from Governmental authorities was secured by J. T. Lonsdale, and the writer was employed by the Bureau of Economic Geology for six weeks in July and August 1952 to collect from the Tertiary deposits.

In February 1962, the writer, together with Malcolm C. McKenna and G. O. Whitaker, of the American Museum of Natural History, and R. M. Alf, of Claremont, California, returned to collect in Big Bend National Park. This was a preliminary trip prior to planning for more intensive searching in the Paleocene beds. Considerable additional material was found, including the first remains of pantodonts, additional multituberculate teeth, and a fragmentary lower jaw of a *Plesiadapis* sp.

During July and August 1962, the writer collected considerable portions of a miacid skeleton (Loc. T14, Pl. II) from the Late Eocene near Cerro Castellan.

Previous workers had been primarily interested in dinosaurs, which probably accounts for the late discovery of the Tertiary mammals. As usual, the Paleocene collection, although containing more variety, was more fragmentary than that from the Eocene. Nonetheless, they contain the first continental Paleocene and Eocene mammals discovered in Texas. Another structural basin containing Early Tertiary vertebrate-bearing beds may now be added to those of the Rocky Mountains region—the Sunken Block of the Big Bend (Udden, 1907a, pp. 80–81), the most southerly of such basins in the United States.

In the summer of 1963, vertebrate-bearing localities were discovered in the silts and tuff mapped on Plate II as "older gravel." The following genera have been tentatively identified: *Miolagus* sp., *Stenomylus* cf. *S. crassipes*, *Oxydactylus* sp., *Nanotragulus* sp., and *Hypsiops* cf. *H. luskensis*. This fauna correlates with that of the Lower Harrison of western Nebraska, and the age of the "older gravel" at these sites (Pl. II, Locs. T11–T13) is Early Miocene. Further collecting will very likely extend these deposits farther southeast. Description of the fossils will have to await further study.

The structural history of the southwestern part of the Park is not modified by this discovery. North and east of Cerro Castellan is a normal fault with lower Chisos tuffs and conglomerate against the "older gravel." This fault is parallel with others in the general vicinity and with the fault along the northeast front of Sierra Ponce and at the mouth of Santa Elena Canyon. If these faults are of the same age, they are post-Early Miocene.

A summary of the stratigraphic positions of the vertebrate faunas as of 1965 is shown in table 10.

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TABLE 10.—Summary of stratigraphic positions of Tertiary vertebrate faunas.

TIME STRAT. UNITS	NORTH AMERICAN PROVINCIAL AGES	ROCK STRATIGRAPHIC UNITS		
TERTIARY — MIOCENE	ARIKAREEAN		OLDER GRAVEL and ALLUVIUM	Geomyid, *Archaeolagus* sp., *Stenomylus* sp., *Oxydactylus* sp., *Nanotragulus* sp., *Hypsiops* cf. *H. luskensis*, rhinoceratid, turtle
OLIGOCENE	CHADRONIAN?	BIG BEND GROUP	CHISOS FORMATION	Brontotheridae, genus indet., turtles. Close to stratigraphic position of Bee Mountain Basalt Member. (Loc. T16)
	DUCHESNEAN			
EOCENE	UNITAN?			*Uintacyon* sp., *Triplopus* sp., turtles. Approx. 900 feet below Bee Mountain Basalt Member.
	BRIDGERIAN		CANOE FORMATION	Brontotheridae, genus indet., *Hyrachyus* sp., *Helohyus* cf. *H. lentus*
	WASATCHIAN		HANNOLD HILL FORMATION	*Phenacodus* cf. *P. primaevus*, *Coryphodon* sp., *Hyracotherium vasacciense*, gastropods, turtles
PALEOCENE	CLARKFORKIAN	TORNILLO GROUP	BLACK PEAKS FORMATION	*Plesiadapis* sp., ?*Claenodon* sp. cf. *C. procyonoides*, *Psittacotherium* cf. *P. multifragum*, *Phenacodus* or *Gidleyina* sp., *Phenacodus* cf. *P. grangeri*, *Periptychus superstes*, pantodonts (3 or 4 genera), pelecypods, gastropods, gar scales, turtles, crocodile. Loc. T1.
	TIFFANIAN			
	TORREJONIAN			cf. *Mimetodon douglassi*, *Psittacotherium* cf. *P. multifragum*, *Tetraclaenodon puercensis*, *Periptychus carinidens*, pelecypods, gar scales, turtles, crocodile
	PUERCAN			Puercan fauna not found

Acknowledgments

Acknowledgment is hereby made to J. T. Lonsdale and R. A. Maxwell and to the staff of the United States National Park Service for their invaluable aid in this undertaking. Illustrations for this paper were drawn by student assistants at The University of Texas whose services were paid from grants made to the writer by The University of Texas Research Institute. Expenses of two trips to Washington, D. C., and New York City for purpose of comparing the Big Bend fossils with other collections were reimbursed from grants made to the writer by the Geology Foundation, The University of Texas.

Previous Work

Late Cretaceous vertebrates are known from Big Bend National Park. Limb bones and vertebrae, identified by S. W. Williston as *Claosaurus*, were reported by Udden (1907a, p. 53). In 1939 a party from the University of Oklahoma, consisting of W. N. McAnulty, D. E. Savage, and Wann Langston, collected dinosaur remains in the vicinity of Glenn Springs. The collection is now at Norman, Oklahoma. In 1940 an expedition from the American Museum of Natural History, New York, made a col-

lection of dinosaur and crocodile material from the Aguja Formation in the vicinity of Glenn Springs, south of the Chisos Mountains, and from localities on and near Tornillo Flat. Brown (1940) stated that the sauropod dinosaur *Alamosaurus* was collected from the Tornillo (Javelina of this report) Formation. During 1939 and the early 1940's, parties from Texas Western College, directed by W. S. Strain of that school, collected dinosaur material under sponsorship of the Work Projects Administration. In 1947, Wann Langston made a small collection of dinosaur material, which is still at Texas Technological College, Lubbock.

At the present time, the Late Cretaceous vertebrate fauna is being studied by E. H. Colbert, of the American Museum of Natural History, and Wann Langston, of the Texas Memorial Museum, Austin. *Phobosuchus riograndensis*, a giant crocodile, has already been described (Colbert and Bird, 1954).

Systematic Descriptions

Black Peaks Formation, Torrejonian Age

Order MULTITUBERCULATA
Family PTILODONTIDAE
cf. MIMETODON DOUGLASSI
Figure 107

Locality.—T2.[7] Between and 100 yards north of two very prominent black igneous peaks on the east edge of Tornillo Flat at the foot of the north end of McKinney Hills, Big Bend National Park.

Stratigraphic position—One hundred forty feet above base of Black Peaks Formation.

Material.—Fragment of a P_4 (B.E.G. 40147–15, fig. 107) is the only material representing this genus, and it is impossible to identify the species from this single fragment. The length of the tooth as estimated from the fragment, which is 5.3 mm long, and the number of serrations (10) would indicate that the specimen had approximately 12 serrations, whereas *M. trovessartianus* has approximately 15. That the Texas material represents a species of *Mimetodon* is probable.



FIG. 107. cf. *Mimetodon douglassi*, fragment of P_4 (B.E.G. 40147–15). ×3.

[7] T1, T2, etc., refer to localities on geologic map, Pl. II.

Order TAENIODONTA
Family STYLINODONTIDAE
Subfamily PSITTACOTHERIINAE
PSITTACOTHERIUM cf. P. MULTIFRAGUM Cope
Figure 108

Locality.—T2 (described, opposite).

Stratigraphic position.—Described, opposite.

Material.—?P^3 (B.E.G. 40147–3, fig. 108a, b); a fragment of an incisor (B.E.G. 40147–3a, fig. 108c); a canine fragment (B.E.G. 40147–3b, fig. 108d); a ?P^3 (B.E.G. 40148–2, fig. 108e, f); an edentulous jaw fragment (B.E.G. 40147–7, not figured).

The teeth of taeniodonts are distinct from those of other groups of mammals but within the group are rather poorly known. The tooth fragments from this locality are too large to belong to *Wortmania*. The enamel on the incisor fragment does not completely invest the tooth as it does in *Wortmania* (Patterson, 1949b). The ?P^3, although slightly worn, shows that the crown pattern had not yet reached the level of cuspidation shown by *Lampadophorus expectatus* of the Tiffanian (Patterson, 1949a, 1949b). The tooth is slightly smaller (see measurements on p. 162) than other taeniodont teeth from locality T1 (Tiffanian) and lacks the buccal extensions of the anterior and posterior cingula, anterior and posterior to the paracone, possessed by the teeth from locality T1.

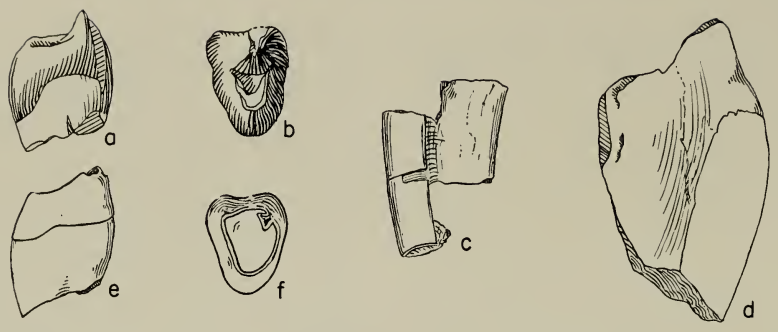


Fig. 108. *Psittacotherium* cf. *P. multifragum* Cope. (a, b) ?P^3 (B.E.G. 40147–3). (c) Incisor fragment (B.E.G. 40147–3a). (d) Canine fragment (B.E.G. 40147–3b). (e, f) ?P^3 (B.E.G. 40148–2). All ×1.

The T2 taeniodont suggests Torrejonian age and in some ways resembles early Torrejonian material in the American Museum of Natural History collections more than it resembles late Torrejonian material. The writer is indebted to Dr. Malcolm C. McKenna for pointing out differences in the premolars from localities T2 and T1.

Order CONDYLARTHRA
Family PHENACODONTIDAE
?TETRACLAENODON PUERCENSIS (Cope)
Figure 109

Locality.—T2 (described on p. 159).

Stratigraphic position.—Described on page 159.

Material.—A left P^4 (B.E.G. 40147–19, fig. 109); anterior half of left M^1 (not figured); left M^2 in fragment of maxilla (not figured).

Various workers have experienced considerable difficulty in distinguishing transitional species of *Tetraclaenodon* from *Phenacodus*. The problem has been reviewed by Gazin (1956, p. 45) and by Dorr (1958, pp. 1224–1225). The small amount of material from Big Bend National Park brings a solution no closer.

The writer has compared the Texas specimens with material in the American Museum of Natural History and concludes that the material from locality T2 more likely falls within *Tetraclaenodon puercensis*, although it may later turn out to be a species of *Phenacodus* or *Gidleyina*. There is a prominent parastyle on the upper molars, but this is also found on teeth from the Torrejonian of the San Juan Basin. A.M.N.H. 16653 possesses a parastyle on M^1, though not quite as prominent as that on the Big Bend molars. The M^2 from locality T2 has a cingulum around the protocone but not the hypocone. None of the specimens examined at the American Museum nor the M^2 from locality T1 have this structure. The metacone on P^4 is larger than in *Tetraclaenodon puercensis*. M^1 and M^2 both possess a mesostyle.



Fig. 109. *?Tetraclaenodon puercensis* (Cope), left P^4 (B.E.G. 40147–19). ×2.

Measurements in Millimeters

	A.M.N.H. 16653		A.M.N.H. 3856		B.E.G. 40147-19-BB	
	Length	Width	Length	Width	Length	Width
P^4	8.1	10.7	7.6	9.2	8.9	9.7
M^1	8.4	11.0	8.0	9.3	8.4	10.2

Family PERIPTYCHIDAE
PERIPTYCHUS CARINIDENS Cope
Figure 110

Locality.—T2 (described on p. 159).

Stratigraphic position.—Described on page 159.

Material.—Right maxillary fragment bearing lingual half of ?P^4 (B.E.G. 40147–4); right M^1–M^2 in maxillary fragment (B.E.G. 40147–17, fig. 110); and left lower jaw fragment in which the trigonid is damaged and the cusp apices missing.



Fig. 110. *Periptychus carinidens* Cope, right M^1-M^2 (B.E.G. 40147–17). ×2.

Only the upper molars are sufficiently well preserved for identification. Hypocones and protostyles nearly in line with the protocones. Smaller than A.M.N.H. 2466 as figured by Matthew (1937, fig. 20).

Black Peaks Formation, Torrejonian Age

LOCALITY NORTH OF TALLEY MOUNTAIN

Family ARCTOCYONIDAE

?CLAENODON sp. cf. C. PROCYONOIDES (Matthew)

Figure 111

Locality.—T10. One mile northwest of B.M. 2742 or 2.3 miles directly southwest of Glenn Springs.

Stratigraphic position.—About 75 feet above base of Black Peaks Formation.

Material.—Left lower jaw fragments with half of M_1 and M_2 lacking some of the labial enamel wall of the crown (B.E.G. 40151–1).

The jaw resembles "*Claenodon*" *procyonoides* but is larger. (M_2 length parallel to ramus, 10.7+ mm; length from paraconid to rear of entoconid, 9.5+ mm). On the basis of this tentative identification, rocks of Torrejonian age are recognized on the south side of the Chisos Mountains.

Black Peaks Formation, Tiffanian Age

Order TAENIODONTA

Family STYLINODONTIDAE

Subfamily PSITTACOTHERIINAE

PSITTACOTHERIUM cf. P. MULTIFRAGUM Cope

Figure 112

Locality.—T1. North side of Tornillo Creek; it is reached by going west to an area of badlands 2 miles from the main road against the northwest scarp of the flat at the foot of the Rosillos Mountains, about 1½ miles south of a small intrusion. This is a general locality area; remains of turtles, crocodiles, and mammals are found over several tens of acres.

Stratigraphic position.—Locality T1 is 750 feet above the base of the Black Peaks Formation.

Material.—Two left P^3 (B.E.G. 40537–26, fig. 112a, b; and B.E.G. 40537–33, fig. 112c, d); a right P^3 (B.E.G. 40537–61, not figured); and poorly preserved skull fragments (not figured).

These specimens represent a taeniodont slightly larger and with better developed anterior and posterior cingula than the psittacothere from locality T2. This seems

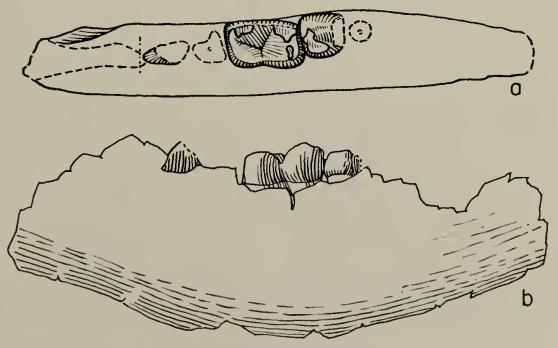


Fig. 111. *?Claenodon* sp. cf. *C. procyonoides* (Matthew), fragmentary lower jaw with half of M_1 and M_2 (B.E.G. 40151–1). (a) Occlusal view. (b) Lateral view. Both ×1.

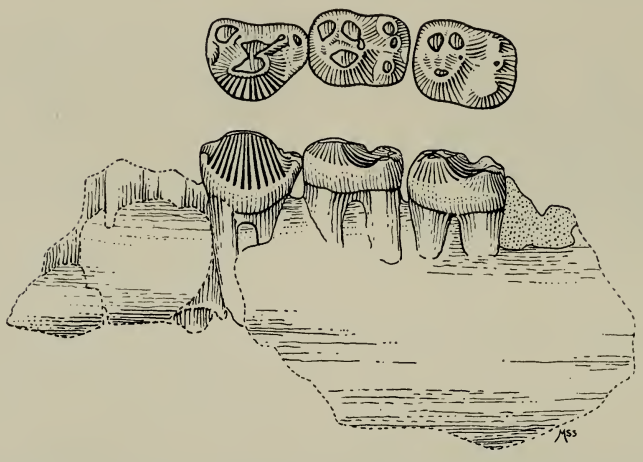


FIG. 112. *Psittacotherium* cf. *P. multifragum* Cope. (a, b) Left P^3 (B.E.G. 40537–26). (c, d) Left P^3 (B.E.G. 40537–33). Both ×2.

to be an advance toward *Lampadophorus expectatus*. Measurements (below) show that the Big Bend teeth are closer in size to each other than to *Lampadophorus* and for this reason they are left with *Psittacotherium*.

Measurements in Millimeters

	Length	Width
?P^3 of *Psitticotherium* cf. *P. multifragum*—		
Locality T2 (Torrejonian)—		
B.E.G. 40147–3	10.0	13.7
B.E.G. 40148–2	10.5	14.5
Locality T1 (Tiffanian)—		
B.E.G. 40537–26	10.1	15.0
B.E.G. 40537–33	10.5	14.0
B.E.G. 40537–61	10.5	13.8
Lampadophorus expectatus	13.3	17.0

Order CONDYLARTHRA
Family PHENACODONTIDAE

PHENACODUS or GIDLEYINA sp.

Figure 113

Locality.—T1 (described on p. 161).

Stratigraphic position.—Described on page 161.

Material.—A right maxilla with poorly preserved M^1–M^2 (B.E.G. 40148–4, not figured); left maxillary fragment with ?M^1 (B.E.G. 40148–4, fig. 113a); right lower jaw with M_1–M_3 (B.E.G. 40148–6, fig. 113b,c).

A medium-sized mesostyle-bearing phenacodont about the size of *Phenacodus? bisonensis*. A strong mesostyle is present on the upper molars, the metaconids are posteriorly placed but still prominent, and the paralophids loop from protoconid to metaconid.

Measurements in Millimeters

	B.E.G. 40148–4	B.E.G. 40148–6		
	?M^1	M_1	M_2	M_3
Length	9.3	7.9	8.7	8.8
Width	11.2	7.4	7.6	7.7

PHENACODUS cf. P. GRANGERI Simpson

Figure 114

Locality.—T1 (described on p. 161).

Stratigraphic position.—Described on page 161.

Material.—A left ?M^2 (B.E.G. 40148–10, fig. 114a); a right P^4 (B.E.G. 40148–13, fig. 114c); and a left M_3 (B.E.G. 40642–1, fig. 114b).

These specimens are tentatively referred to *P. grangeri* and represent an advanced phenacodont comparable to that Tiffanian species, although they are even larger than the type.

Measurements in Millimeters

	B.E.G. 40148–13 P^4	B.E.G. 40148–10 ?M^2	B.E.G. 40642–1 M^3
Length	10.7	13.1	12.5
Width	12.5	15.5	9.2

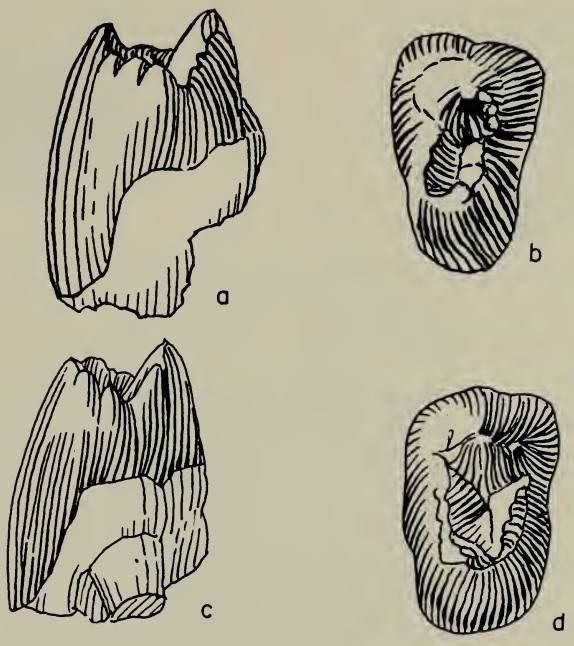


Fig. 113. *Phenacodus* or *Gidleyina* sp. (a) Left ?M^1 (B.E.G. 40148–4). (b, c) Right lower jaw with M_1-M_3 (B.E.G. 40148–6). All ×2.

Family PERIPTYCHIDAE

PERIPTYCHUS SUPERSTES

Figure 115

Locality.—T1 (described on p. 161).

Stratigraphic position.—Described on page 161.

Material.—A fragmentary ramus of a lower jaw with P_4–M_2 (B.E.G. 40537–59).

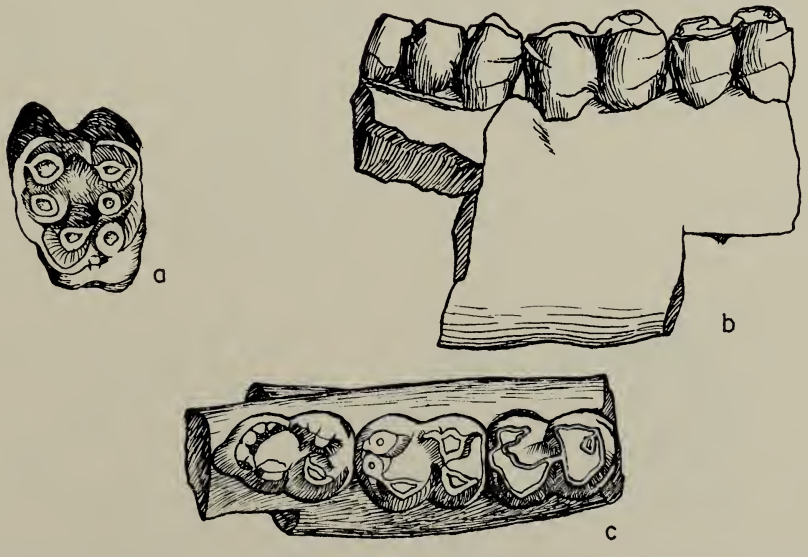


Fig. 114. *Phenacodus* cf. *P. grangeri* Simpson. (a) Left ?M^2 (B.E.G. 40148–10). (b) Left M_3 (B.E.G. 40642–1). Both ×2. (c) Right P^4 (B.E.G. 40148–13). ×4.

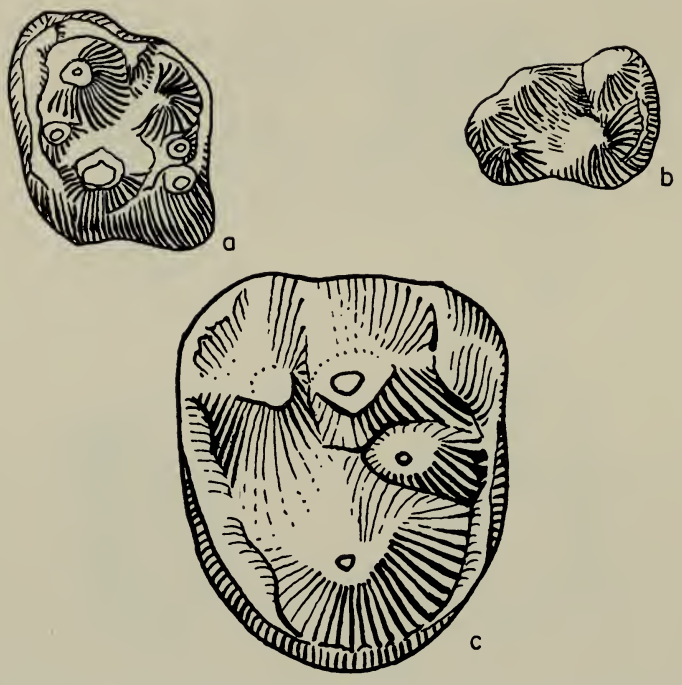


FIG. 115. *Periptychus superstes*. Right mandibular fragment with P_4-M_2 (B.E.G. 40537–59). ×1.

Periptychus superstes Matthew in Simpson (1935) was described as having premolars much smaller than in *P. rhabdodon*. In B.E.G. 40537–59, M_1 is slightly longer than P_4 and at its maximum width M_1 is only 0.01 mm narrower than P_4. Unfortunately, the M_3 of the Texas specimen was not preserved so it is impossible to tell at this time if an elongate heel was present.

		Length	Width
Locality T1—			
Periptychus superstes	P_4	13.5	10.7
B.E.G. 40537–59	M_1	13.7	10.6
	M_2	13.0	11.2
Locality T2—			
Periptychus carinidens	P_4	11.7@	....
B.E.G. 40147–4	?M_2	9.4	9.1
B.E.G. 40147–17			
Tiffany, Colorado—			
Periptychus superstes	P_4	12.3	9.1
(type)	M_1	11.3	9.2
A.M.N.H. 17181	M_2	10.5	9.2
	M_3	14.6	8.9
San Juan Basin, New Mexico—			
Periptychus rhabdodon	P_4	12.	12.
A.M.N.H. 3627	M_3	11.5	9.
(from Matthew (1937) after Cope)			
Periptychus rhabdodon	P_4	13.	10.
(from Cope, 1884,	M_1	11.	9.
p. 394)			

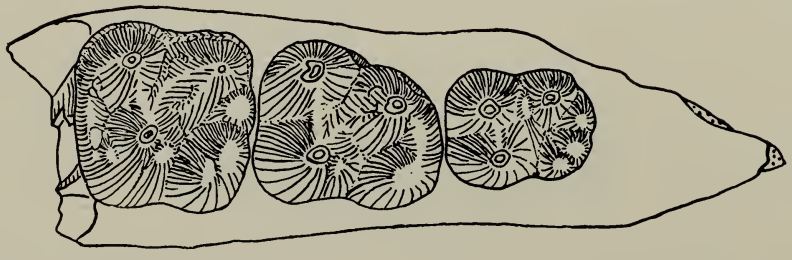


FIG. 116. *Phenacodus* cf. *P. primaevus* Cope. Lower jaw with M_1-M_3 (B.E.G. 40143–1). ×2.

Hannold Hill Formation, Wasatchian Age

Order CONDYLARTHRA
Family PHENACODONTIDAE
Genus PHENACODUS
PHENACODUS cf. P. PRIMAEVUS Cope

Figure 116

Locality.—T4. Tornillo Creek crossing, Tornillo Flat. Designated "Oil House" in fossil accession catalogue of the Bureau of Economic Geology. North side of upper Tornillo Creek crossing and east of the highway at the fossil exhibit.

Stratigraphic position.—The quarry site is about 370 feet above the base of the Hannold Hill Formation.

Material.—A single jaw fragment (B.E.G 40143–1), containing M_1, M_2, and a partially erupted M_3, was found as float with a large quantity of *Coryphodon* scrap below the quarry site. There is no doubt but that it come from the same approximate level as was the quarry site.

Measurements in Millimeters

	Length	Width
M_1	12.3	12.0
M_2	12.	10.5

The teeth have the swollen appearance of *P. robustus;* they certainly belong to a larger species but are not as large as teeth of *P. robustus.* Figures given by Simpson (1937, p. 18) show that the M_1 of the Wyoming specimens is not as square as that of the Big Bend specimen; however, the Big Bend specimen resembles *P. robustus* in this character. The significance of this character will only be determined when more specimens are available.

Order PANTODONTA
Family CORYPHODONTIDAE
Genus CORYPHODON
CORYPHODON sp.

Figures 117, 118

Locality.—T4 (described, above). T5, foot of Hannold Hill; also designated "T. T." in the Bureau of Economic Geology accession catalogue. Two low pink mounds approximately 50 yards east of the main highway, south edge of Tornillo Flat. T6, in lignite bed 20 yards west of highway opposite two prominent mesas (brown topped) which are on east side of highway and on the south side of Tornillo Creek, Tornillo Flat. T7, 50 yards east and the area to the south of Grapevine Spring, southwest corner of Tornillo Flat.

Stratigraphic position.—T4 is approximately 370 feet and T5 approximately 430 feet, respectively, above the base of the Hannold Hill Formation. Stratigraphic position of localities T6 and T7 is uncertain.

Material.—A considerable quantity of *Coryphodon* material was collected, most of which came from a quarry that was opened at locality T4. Two complete but somewhat crushed skulls (B.E.G. 40143–30), two lower jaws (B.E.G. 40143–6), and disarticulated vertebrae, ribs, and limb bones were found within what was obviously an old stream channel. The upper dentition of B.E.G. 40143–30 (fig. 117) and the lower dentition of B.E.G. 40143–6 (fig. 118) are figured. The only associated bones were those of a front foot, which was completely articulated. The quarry site had not been exhausted by the end of the field season, and at the writer's suggestion and with his assistance, the Park Service continued to uncover more bones, all of them *Coryphodon,* in order to make an *in situ* field exhibit. A shelter was constructed and the exhibit covered with glass so that the bones are now protected from the weather. So far as known, this is the only *in situ* exhibit of Tertiary mammal bones in a National park.

It is exasperating that the most plentiful and best-preserved mammalian remains found in Big Bend National Park are not capable of being identified as to species. As other workers have pointed out, the taxonomy of the genus is greatly in need of revision but to do this would be a major undertaking and is not in the province of this paper. Until such revision is done, however, it is impossible to do more than guess whether the Big Bend material constitutes a new species or with which of the



FIG. 117. *Coryphodon* sp., left P^1-M^3 (B.E.G. 40143–30). ×1.

many species of *Coryphodon* the material should belong. At present the writer can do little more than call attention to this well-preserved material, which will add to the task before some future revisor.

Order PERISSODACTYLA
Family EQUIDAE
Genus HYRACOTHERIUM
HYRACOTHERIUM VASACCIENSE (Cope)
Figure 119

Locality.—T4 and T5 (described on

p. 165). T6, on the west side of the highway at the foot of Hannold Hill, Tornillo Flat.

Stratigraphic position.—Same as given previously for localities T4 and T5 (p. 165). Uncertain for locality T6, although known to be higher in the section than T4.

Material.—The posterior part of a crushed skull (B.E.G. 40143–14, fig. 119a), with M^1 to M^3 of both sides (M^1 of right side not figured), and the lower jaw of the same individual, with the right P_4 to M_3 (fig. 119b,c) and the left P_4 and M_2 and M_3, were found in the quarry at locality T4. A left lower jaw fragment (B.E.G. 40143–2) with P_4 to M_3 was also found at T4. Isolated left P^3 and P_3 (B.E.G. 40144–1) were found as float in the matrix at locality T5. The lower end of a left femur (B.E.G. 40150–1) was found on the west side of highway in south end of Tornillo Flat.

These specimens were sent to D. B. Kitts who at the time was studying *Hyracotherium* at the American Museum of Natural History. Kitts' (1956) revision of the genus was based on the structures of P3 and P4, so that he was uncertain as to the specific assignment of the Big Bend material. He tentatively referred the material to *H. angustidens* or *H. vasacciense*. The premolars (B.E.G. 40144–1) were not available when Kitts examined the material. They were discovered later during preparation of a block containing *Coryphodon* bones. P^3 does not have quite as molarized appearance as one would expect to be typical of *H. vasacciense*. The protoconule is large and anterior to a line from the protocone to the paracone, for which reasons the writer refers this material to *H. vasacciense*.



FIG. 118. *Coryphodon* sp., right I_1-M_3 (B.E.G. 40143–6). ×½.

Canoe Formation, ?Bridgerian Age

Order PERISSODACTYLA
Family BRONTOTHERIIDAE

Genus indet.

Figure 120

Locality.—T9. About halfway between Panther Junction and the foot of Hannold Hill, east of an old gravel road to the edge of the Pleistocene gravel where there is the site of an old gravel crusher. About half a mile east is an area of light-colored sandstones, clays, and white tuffaceous beds. Designated "white amphitheater" in Bur-

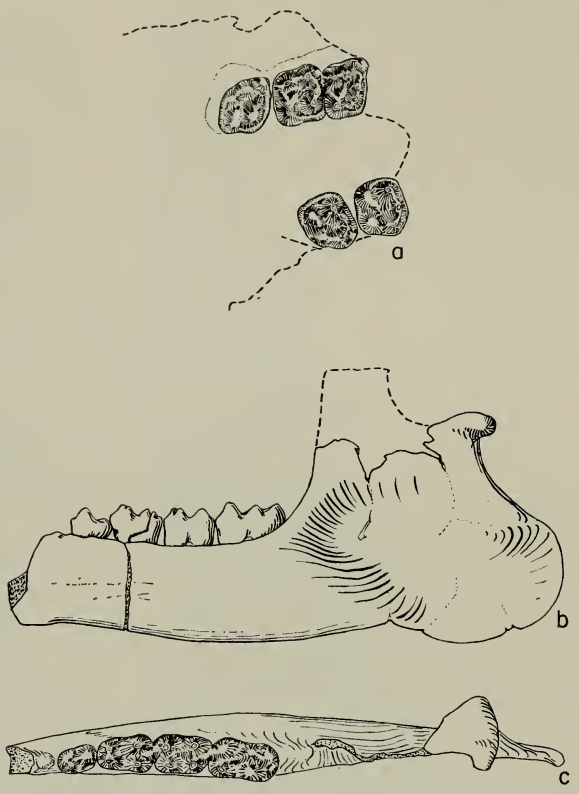


Fig. 119. *Hyracotherium vasacciense* (Cope) (B.E.G. 40143–14). (a) Left M^2-M^3, right M^1-M^3. (b, c) Right lower jaw with P_4-M_3. All ×1.

eau of Economic Geology accession catalogue.

Stratigraphic position.—About 525 feet above the base of the Big Yellow Sandstone Member, Canoe Formation.

Material.—A fragment of an upper cheek tooth (B.E.G. 40146–1) of a small titanothere. Although about the size of a small species of *Paleosyops*, it cannot be assigned to that genus because of the inadequacy of the material. It would appear to be larger than any tooth of *Eotitanops*.



Fig. 120. Brontotheriidae, genus indet., upper molar fragment (B.E.G. 40146–1). × 1.

Family HYRACHIDAE
Genus HYRACHYUS
HYRACHYUS sp.
Figure 121

Locality.—T8. Cross-bedded yellow sandstone and conglomerate, Big Yellow Sandstone Member of Canoe Formation, prominent southeastward-plunging syncline west of the highway in the northern part of Tornillo Flat. Designated "Canoe" in Bureau of Economic Geology accession catalogue.

Stratigraphic position.—Big Yellow Sandstone Member of the Canoe Formation. The tooth was taken from a boulder that was float just below the outcrop of the sandstone. Its position in the Big Yellow Member is unknown, but there is no question that the boulder was eroded from the Big Yellow.

Material.—A single molar tooth (B.E.G.

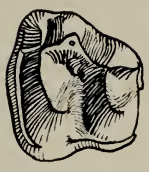


Fig. 121. *Hyrachyus* sp., upper molar (B.E.G. 40145–1). ×1.

40145–1) can safely be attributed to the genus *Hyrachyus*. It is impossible to be certain of the identification of the tooth, and therefore it is useless to speculate concerning the species.

Order ARTIODACTYLA
Family CHOEROPOTAMIDAE
Genus HELOHYUS
HELOHYUS cf. H. LENTUS
Figure 122

Locality.—T9 (described on p. 167).

Stratigraphic position.—Described on page 167.

Material.—Two lower jaw fragments (B.E.G. 40146–2, fig. 122a, and B.E.G. 40146–4, fig. 122b) each containing an essentially complete M_3 and fragmentary M_2.

These specimens have been compared with those of the same species in the United States National Museum (U.S.N.M. 17711) and the American Museum of Natural History (A.M.N.H. 12150). Both Big Bend specimens match very closely with the comparable teeth at these museums.

Such fragmentary material can add nothing to the biological knowledge of the genus, but the specimens are important for the stratigraphic information they furnish.

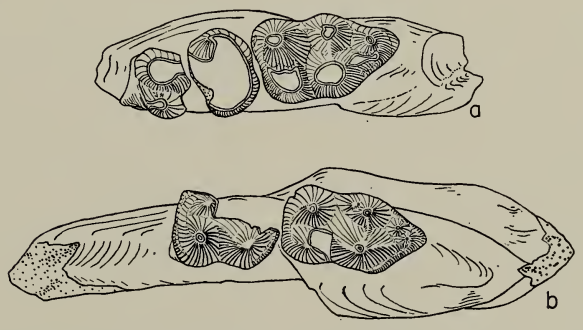


Fig. 122. *Helohyus* cf. *H. lentus*. Fragmentary lower jaws, not from same individual, with fragmentary M_2-M_3. (a) B.E.G. 40146–2. (b) B.E.G. 40146–4. Both ×1.

GEOLOGY OF INTRUSIVE IGNEOUS ROCKS[8]

John T. Lonsdale and Ross A. Maxwell

Occurrence of Igneous Rocks

Intrusive igneous rocks occur at many places in Big Bend National Park; their distribution is shown on Plate II and a brief description of most of them is given in table 13 (pp. 189–244). The intrusive masses include dikes, sills, laccoliths, plugs and various irregularly shaped bodies. Intrusions are largest and most abundant in a broad northwest-southeast belt centering around the Chisos Mountains, mostly in an area bounded by Mesa de Anguila on the west and the Santiago Mountains and Sierra del Carmen on the east (Pl. II).

Probably the entire area was once covered by Tertiary lavas and pyroclastic rocks, and some of the intrusive bodies were probably feeders for the extrusions. The volcanic rocks are now nearly continuous from Punta de la Sierra (Pl. II; E–F, 15–16) northward to the Christmas Mountains (Pl. II; P–S, 11–12). Isolated patches are present at Sierra Aguja (Pl. II; J–K, 5–6) and also in some places southwest of the Christmas Mountains. The greatest thickness of extrusive rocks in the Park is in the Chisos Mountains, but some distance from the Chisos Mountains the volcanic rocks are thin or absent. The decrease in thickness away from the mountains may be due to (1) original thinning of the volcanic accumulation away from the Chisos Mountains which were probably a center of extrusive activity, (2) more vigorous erosion of volcanic rocks away from the mountains, or (3) a combination of both 1 and 2.

Lonsdale (1940) mapped and described the intrusive rocks in the Solitario and discussed some of the extrusive rocks along Fresno Creek to the west and southwest (Pl. I). Yates and Thompson (1959) mapped and described both intrusions and extrusions in the Terlingua district; farther north the intrusions and extrusions in the Agua Fria quadrangle were mapped and described by Moon (1953), and Erickson (1953) reported on the igneous rocks in the Tascotal Mesa quadrangle. Dietrich (1966) reported on both intrusions and volcanic rocks in the Bofecillos Mountains west of the Solitario (Pl. I). Bloomer (1949a) reported on the igneous rocks in the Christmas Mountains north of the Park. Both intrusions and extrusions are present in the Black Gap area east of the Sierra del Carmen and in Mexico southeast and south of the Park and also in Mexico west of Mesa de Anguila.

The intrusive igneous rocks, because of their abundance, diversity, petrographic character, and topographic expression, are an important part of the geology in the Park. Generally they are well exposed, although parts are covered by talus. Many of the rocks have been weathered or altered, so that fresh specimens are not always available. Most of them are fine grained.

The intrusive rocks invade all Gulfian sedimentary formations, as well as most Tertiary rock units; some lie in the Comanchean formations along the southern flank of the Christmas Mountains and at the southern end of the Santiago Mountains. The Rosillos Mountains, north of the Park boundary, and the McKinney and Grapevine Hills include intrusions that are generally concordant with Gulfian formations and are laccoliths. Many of the thick tabular masses are sills, but some are low-angle crosscutting bodies. Both types have

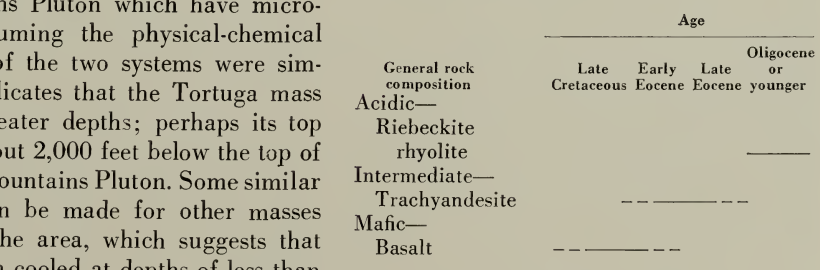
[8] John T. Lonsdale, former Director of the Bureau of Economic Geology, died before the chapter on igneous rocks was prepared. The following discussion was written and the tables compiled from Lonsdale's notes by Maxwell.

arched the overlying beds and are gradational with laccoliths; the Croton—Paint Gap Hills and Chilicotal and Talley Mountain masses are examples. The intrusions at Maverick, Ward, Pulliam, Tortuga, and Dominguez Mountains, Elephant Tusk, Backbone Ridge, Sierra Quemada, and many smaller bodies are crosscutting stalks or plugs. Sills are conspicuous along the west sides of the Sierra del Carmen, Mariscal Mountain, and Mesa de Anguila. Scores of dikes from a few inches to 100 feet thick occur throughout the area. The dike swarm radiating from Dominguez Mountain is the most spectacular occurrence (Pl. II).

The intrusive rocks are hypabyssal and probably cooled at less than a few thousand feet below the surface at the time of intrusion. About 2,000 feet of intrusive igneous rocks form nearly vertical exposures in the Chisos Mountains Pluton. The sedimentary cover has been eroded from above the mass and its original thickness is unknown. The Tortuga Mountain intrusive (Pl. II; J, 17) gives the best opportunity to estimate the depth at which the magma crystallized. The intrusive mass is a medium- to coarse-grained granite that intruded Upper Cretaceous rocks and cooled beneath about 4,300 feet of Tertiary rocks. The rocks in the Tortuga intrusion are mineralogically similar to rocks in the Chisos Mountains Pluton which have microfabrics. Assuming the physical-chemical parameters of the two systems were similar, this indicates that the Tortuga mass cooled at greater depths; perhaps its top cooled at about 2,000 feet below the top of the Chisos Mountains Pluton. Some similar analogies can be made for other masses throughout the area, which suggests that some of them cooled at depths of less than 2,000 feet.

The intrusive masses that tend to be composed of similar rocks are normally found in local areas, which suggests a common source and probably a comparable age. Quartz-olivine rocks form the McKinney and Grapevine Hills and the Rosillos Mountains. Quartz-riebeckite rocks form Ward, Pulliam, and Tortuga Mountains and Sierra Quemada. Quartz-feldspar porphyry dikes and sills are common in the Chisos Mountains. Basalt with analcite-syenite bands is common in sills along the west side of the Sierra del Carmen, Bone Spring, and Mesa de Anguila. Thicker masses, probably laccolithic, consisting of analcite rock are Rattlesnake and Peña Mountains.

Age of igneous rocks.—Many dikes, sills, and other intrusive masses were emplaced in the Gulfian formations, and their petrographic characteristics and regional setting suggest that some were formed during one period of magmatic activity. At Mariscal Mountain, Cow Heaven anticline, and Tortuga Mountain, mafic sills have been concordantly deformed within the sedimentary rocks that were folded during the Laramide orogeny and are believed to be of Late Cretaceous age (pp. 286–290). Some intrusions, mostly acidic (Ward, Pulliam, and Hayes Ridge plugs on Burro Mesa), have deformed the South Rim Formation and are post-Oligocene age (pp. 290–292). The intermediate group, which includes the McKinney and Grapevine Hills, Glenn Springs, Maverick, probably Government Spring, Panther, Little Christmas, and perhaps the Dominguez mass, are probably Late Eocene. These age relations are graphically shown below:



Composition of igneous rocks.—The igneous rocks in Big Bend National Park range from alkali basalt containing about 44 percent SiO_2 to riebeckite rhyolite and granite with about 76 percent SiO_2. The suite of rocks constitutes a part of one of the several alkalic subprovinces along the Rocky Mountain Front that extends from

Montana to Texas and southward into Mexico. Brief descriptions are given in table 13; chemical analyses, norms, and modes for some are given in table 14 (pp. 245–265).

Gottfried, Moore, and Caemmerer (1962, pp. 71–72) discussed the silica content, the lime to soda-potash ratio, and the thorium and uranium content for 27 rock samples from the Park. The siliceous rocks in the range from about 70 to 77 percent silica have lime to potash ratios ranging from about 0.03 to about 0.1, indicating they are extremely lime-poor. In these rock samples the thorium content ranges from about 25 to 45 ppm and the uranium content from 9 to 45 ppm. Both thorium and uranium show a rather systematic increase from the mafic to the silicic rocks, but the thorium to uranium ratio is nearly the same over the entire composition range. Except for two samples, the thorium-uranium ratio falls between 2 and 3½.

Analcite-Bearing Rocks

In the Big Bend region there is a distinctive suite of alkalic rocks containing analcite which forms small laccoliths, sills, and dikes. Rocks in the suite in the Terlingua-Solitario area have been described by Lonsdale (1940) and some of those in the Park area by Lonsdale and Dickson (1948a, 1948b). Further work has shown that analcite-bearing rocks occur throughout the intrusive igneous masses of the southern Big Bend region but their extent beyond this is not yet known. They have been reported as far as about 200 miles northwest of the Park as well as south of the Rio Grande. The masses containing analcite-bearing rocks in this general region are older than most masses of siliceous alkalic rocks.

The more abundant types of the rocks of the analcite suite are dark basaltic, gabbroic, or dioritic but they possess features which distinguish them from common rocks of these types. The dark analcite-bearing rocks include bands, stringers, blebs, and larger bodies of lighter colored syenite with calcite and zeolite veins that on superficial examination appear to be individual intrusions (figs. 123, 124, 125).

The occurrence of analcite in this rock suite has been emphasized because (1) all of its members contain analcite, (2) the mineral has not been recognized in any rocks of the region other than those of the analcite suite, and (3) the cooling history of the magma appears to have been similar in all masses with the formation of analcite as an essential feature. Most rocks in the suite contain abundant plagioclase (andesine and labradorite) and alkali feldspar (orthoclase, sodic orthoclase, and anorthoclase) with augite, olivine, analcite, ore minerals, and apatite. There is considerable range in the plagioclase-alkali feldspar ratio so that the suite includes basalt, trachybasalt, trachydolerite, syenogabbro, syenodiorite, and plagioclase syenite. In the more mafic types where plagioclase is a prominent constituent, augite and olivine are abundant and augite is commonly titaniferous. Where alkali feldspar is abundant and the total feldspar content is large, olivine occurs in small amounts and augite is commonly rimmed with aegirine; biotite or hornblende, or both, along with aegirine, commonly are present in minor amounts. In masses containing nepheline-bearing rocks, analcite is not a major constituent except in the groundmass.

Chemical analyses of analcite-bearing rocks from the Park and adjacent areas are shown in table 14; these analyses do not show those variations in the suite which are characterized by high titanium and phosphorus. A few specimens contain as much as 1 percent of apatite. Late zeolitization is characteristic, and it is difficult to secure sufficiently fresh specimens to warrant analysis.

Many masses contain syenite which appears to be the product of differentiation. All the masses except a few thin dikes and sills contain syenitic stringers and veinlets, a fraction of an inch to 2 inches thick, and isolated segregations not exceeding a few inches in diameter. In many of the sills, syenite layers persist for long distances. They generally parallel the boundaries of



FIG. 123. Large bleb or pod (25 × 20 × 15 feet) of light-colored analcite syenite rock jutting out in bold relief at Rattlesnake Mountain (Pl. II; K–L, 8).



FIG. 124. Light-colored stringers (up to 3 inches thick) and irregular bodies of analcite syenite at Rattlesnake Mountain.

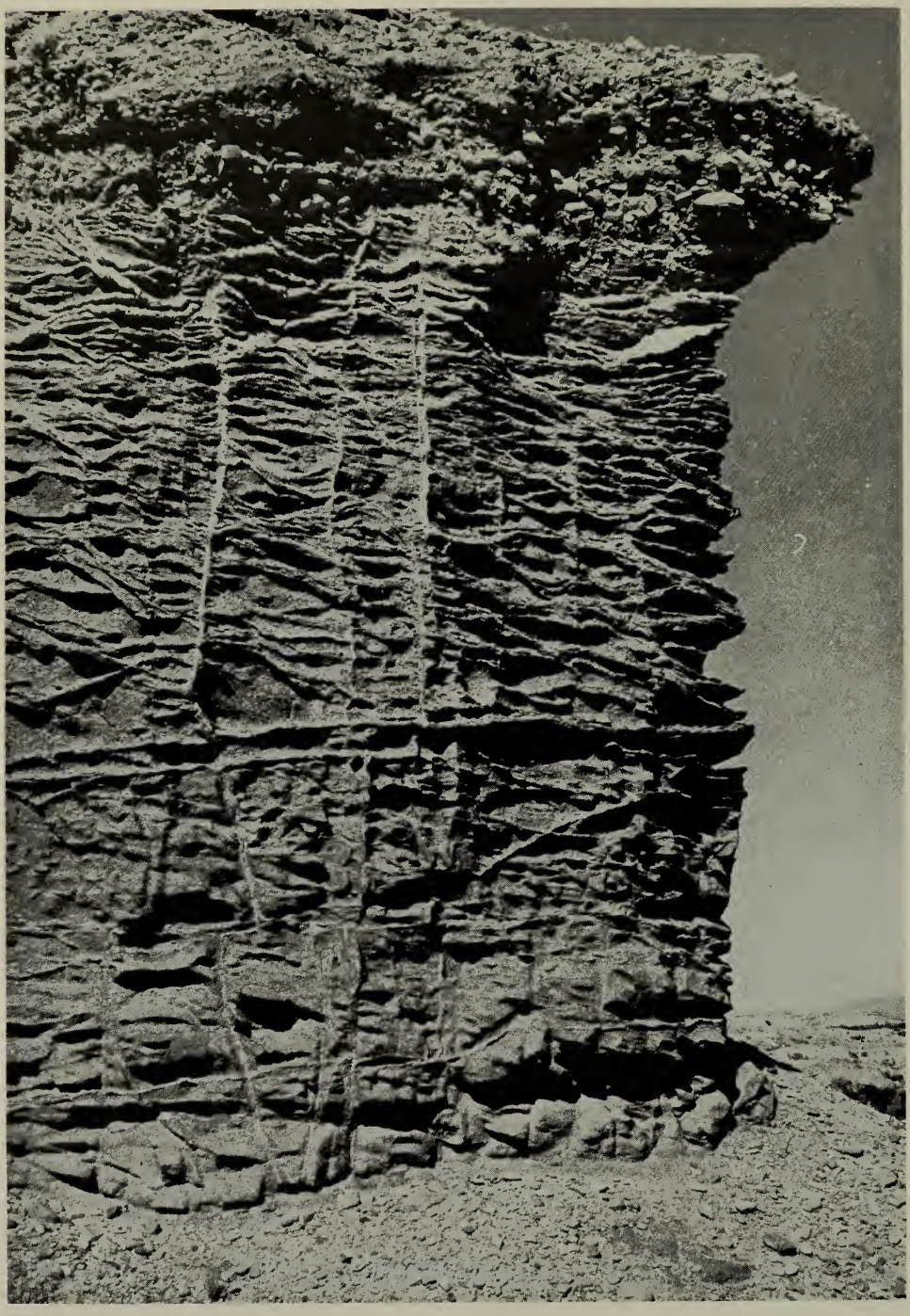


FIG. 125. Network of calcite veins (up to 2 inches thick) in analcitic rock north of Sierra San Vicente (Pl. II; E, 22).

the sills and have sharp contacts with main rock. Smaller masses commonly contain only two rock types—the main rock, a plagioclase-alkali feldspar-augite-olivine rock, and the syenite layers. Thicker sills and laccolithic masses contain a greater variety of rock types.

The most abundant syenite is fine to medium grained, light colored, and contains abundant alkali feldspar (anorthoclase or soda-microcline), as well as some oligoclase or albite, aegirine pyroxene, biotite, and hornblende with ore minerals, apatite, and analcite. A brief description of the analcite rocks from 52 localities is given in table 13, and three of the more important occurrences are described below.

The chemical analyses, norms, and modes of 13 analcite rock samples from the Big Bend are given in table 15 (pp. 266–268) and are also reported in table 14 as numbers 53, 62, 66, 74, 81, 87, 91, 93, 95, 100, 101, 111, and 114.

Rattlesnake Mountain.—The best exposure of analcite rock is at Rattlesnake Mountain (Pl. II; K–L, 8), where a laccolith has an exposed area of about 2½ square miles. The western part of the mass has been eroded into a steep cliff; only a few remnants extend over the top so that the upper surface of the mass is also well exposed.

Most of the laccolith is a medium-grained, dark-gray, analcite-plagioclase syenite with plagioclase close to An_{50}. In this rock, especially well exposed on the west-facing margin, are many layers and irregular masses of lighter colored syenite which are interpreted as a product of differentiation. One mass, 25 x 20 x 15 feet, juts out in bold relief on the slope (fig. 123). Extending from it are numerous veinlike bodies of the same material (fig. 124). Two of these are 5 feet thick near the mass but only 1 foot thick 100 feet from it. Many small layers extend from the larger body and the two larger layers. In addition, there are many separate small layers and small irregular bodies. The whole west-facing cliff is riddled with syenite bodies. Veins of later zeolites as much as a few inches thick cut all of these and in turn are cut by veins of calcite of the same size.

Syenite bodies are as prominent in exposures on the top of Rattlesnake Mountain as in the west-facing cliff and show the same features, especially at the same level as that of the prominent mass in the west-facing cliff.

The most common syenite in Rattlesnake Mountain is medium to fine grained and rich in analcite and alkali feldspar with some sodic plagioclase (albite or oligoclase) and sodic pyroxene. However, the composition and texture vary even in thin layers. A layer composed entirely of syenite may grade laterally into a coarse-grained rock of somewhat different mineral composition, or show borders of coarse material and centers of fine-grained analcite syenite. Miarolitic cavities up to a few inches in diameter occur in the fine-grained syenite. They are lined with subhedral analcite crystals, subhedral aegirine crystals, laths of orthoclase, rare laths of albite, tiny needles of apatite, rare minute octahedral magnetite, flakes of biotite, and grains of epidote(?). Elongate openings a fraction of an inch to several inches wide and from several inches to a foot in length are bordered by pegmatite composed of laths of alkali feldspar, sodic pyroxene, and analcite.

The following crystals have been identified from the pegmatite and miarolitic cavities: analcite, aegirine, amphibole, orthoclase (with rare albite centers), apatite, calcite, magnetite, biotite, and epidote(?)

The feldspar and aegirine are intergrown in blades, rosettes, and perfect crystals. Commonly one is included in the other; probably the aegirine is more commonly included in the feldspar. In many intergrowths, the feldspar rosettes grow on top of the aegirine. The greatest concentration of feldspar is on the contact edges of the pegmatite-lined crevices, and from this it might be reasoned that the feldspar formed first and is the oldest mineral present.

Euhedral feldspar crystals included in

analcite crystals were not observed, but feldspar rosettes are plastered on the sides of and overlap the euhedral analcite. Formation of feldspar both preceded and followed the analcite formation.

Aegirine occurs as euhedral to subhedral prisms, blades, and sheaths. Commonly, aegirine prisms are included in both feldspar and analcite; very fine needles or hairs of aegirine are included in analcite. In thin sections, sheaths of aegirine terminate abruptly at well-developed analcite crystal faces. Occasionally, discrete aegirine crystals occur on top of well-developed analcite crystals while in some thin sections the analcite crystals appear to have had continued growth. Apparently, aegirine crystallized before, after, and with analcite.

In a few vugs, which also contain biotite, magnetite is crystallized in well-developed octahedra on feldspar, aegirine, and analcite. The magnetite apparently formed late and everywhere occurs on the inside of the cavities. Small reddish aggregates and dendritic threads of ore minerals were observed in one or two cavities. Biotite books are sparse and probably biotite is not as common in the pegmatites as in the main rock.

Amphibole, which is a blue-green to brownish hornblende(?), was found in a few cavities; a similar amphibole also occurs in the main rock. The amphibole is closely associated with aegirine and/or biotite and occurs in cavities with apatite. It has not been determined whether the amphibole occurs without apatite.

Calcite is younger than the analcite where both occur in the same cavity. Epidote(?) is closely associated with the aegirine and some of it has euhedral terminations. It is also found in stringers and blades in the feldspar.

The analcite is a late mineral with rare slight birefringence and all indices close to 1.485. One analysis shows only 0.22 percent K_2O. In the mafic rocks some analcite is of the type which has been called primary (Lonsdale and Dickson, 1948b, p. 8). It also replaces other minerals and rarely forms ocelli (Lonsdale and Dickson, 1948b, p. 8). In these rocks, especially in the larger interstices, analcite encloses numerous minute euhedral crystals of practically all other minerals of the rock. In the syenite differentiates, analcite is largely interstitial and there is less evidence that it replaced other minerals. In the miarolitic cavities and pegmatite bodies, the analcite is part of an assemblage which includes aegirine, biotite, amphibole, apatite, alkali feldspar, and magnetite. It seems reasonable to conclude that much of the analcite formed at least as early as the pegmatite stage.

The evidence from Rattlesnake Mountain and other less perfectly exposed masses appears to indicate that the varied rock types in this group of minor intrusions originated by crystallization in closed system. It is only the mafic intrusions that contain the profusion of syenitic rocks; the more silicic analcite-bearing rocks do not contain them. Probably the magmas were not in equilibrium during crystallization and reaction proceeded actively. Rapid crystallization produced numerous slightly different rocks that are mostly highly alkalic analcite syenite; this rock occurs in large bodies only in the larger masses like Rattlesnake Mountain.

Peña Mountain.— In Peña Mountain (Pl. II; J, 8–9), about 1½ miles south of Rattlesnake Mountain, analcite-bearing rocks form a north-facing escarpment that may be a continuation of the Rattlesnake rock brought to the surface by faulting. This mass is about 125 feet thick and is well exposed in several arroyos for half a mile. The bottom margin is a chilled, very fine basalt that is rich in augite and olivine with a little analcite in a feldspathic groundmass. The main rock is a dark-gray, medium-grained analcite syenogabbro that is cut by bands and stringers of analcite as much as 4 inches thick and mineralogically like the chilled border. Syenite bands are rare and are about half an inch to 4 inches thick. Prominent later zeolite veins cut all rock in the mass and are very ir-

regular. The rocks in Peña and Rattlesnake Mountains are similar, but the differentiates are less prominent at Peña Mountain.

Bone Spring.—North of Bone Spring, in the northern part of the Park, is a sill about 100 feet thick (Pl. II; Q–R, 1). The principal rock is medium-grained, analcite trachydolerite with a salt-and-pepper texture; the chilled margin is analcite basalt. Throughout the mass are layers of fine-grained analcite syenite as much as 6 inches thick but small in volume as compared with the total rock. Most layers are traceable only a few yards, feeders are not apparent, and the layers appear to be segregations generally parallel to the upper contact of the sill.

Associated with the analcite layers are bands, a few inches thick, of rock with abundant acicular hornblende crystals as much as 2 cm long. This mineral, as well as gray to purplish augite, laths of anorthoclase, andesine, long prisms of apatite, and ore grains, is embedded in a felty feldspathic groundmass in which there are grains and prisms of bright green pyroxene and grains of alkali feldspar. Analcite occurs as replacements of plagioclase interstitially and in discrete masses enclosing earlier minerals. Later zeolitization (natrolite) has altered much of the rock.

Riebeckite Rhyolite

Most of the riebeckite rhyolite in Big Bend National Park is similar to the paisanite (Osann, 1896) named after Paisano Pass in the Davis Mountains. Numerous dark gray-blue streaks or irregularly shaped spots give a distinctive appearance to an otherwise light-colored rock.

The paisanite of Osann has a light-gray to white, very fine-grained to compact, micropoikilitic groundmass composed of idiomorphic feldspar enclosed in quartz with minor quantities of apatite, zircon, and ore minerals. Feldspar is commonly the dominant mineral, but feldspar and quartz form nearly equal proportions in a few specimens. Dark-colored pleochroic hornblende intergrown with the groundmass forms the dark gray-blue mass that gives the rock its distinctive appearance. The amphibole is riebeckite which occurs as parallel prismatic grains and spongy, porous masses. Both irregular boundaries and crystal faces are present in the riebeckite intergrowths.

Location and brief description of several of the riebeckitic masses within the Park are given in table 13; some of them are described separately below.

Chisos Mountains Pluton.—The Chisos Mountains Pluton forms the roughly crescent-shaped belt of intrusive igneous masses in the northwestern and western third of the high central part of the Chisos Mountains (Pl. II; K–M, 15–17). Peaks in the pluton, together with eminences toward the east and southeast that are carved from lava and pyroclastic rocks, form the most imposing scenery in the Park. The higher peaks of the pluton stand 2,500 feet above the general level of the Basin and about 3,500 feet above most of the country on the convex side of the crescent-shaped intrusion.

Pulliam Peak, Vernon Bailey Peak, and Ward Mountain are parts of a continuous outcrop of intrusive rock that extends in an arc from northeast to southwest and partly encloses the Basin (Pl. II; L, 16). Dikes, sills, and minor irregular masses in the Basin and adjacent areas are part of the igneous complex, but some bodies are listed separately in table 13.

Most of the contacts between the pluton and the country rock are concealed by talus. The Chisos Formation crops out at a few places along the convex side and stands at various attitudes. Near the northeast flank of Pulliam Peak (Pl. II; M, 17), the Chisos Formation appears to be arched over the pluton; along the north flank of the peak (Pl. II; M, 15–16) the beds dip at low angles toward the pluton. Near Blue

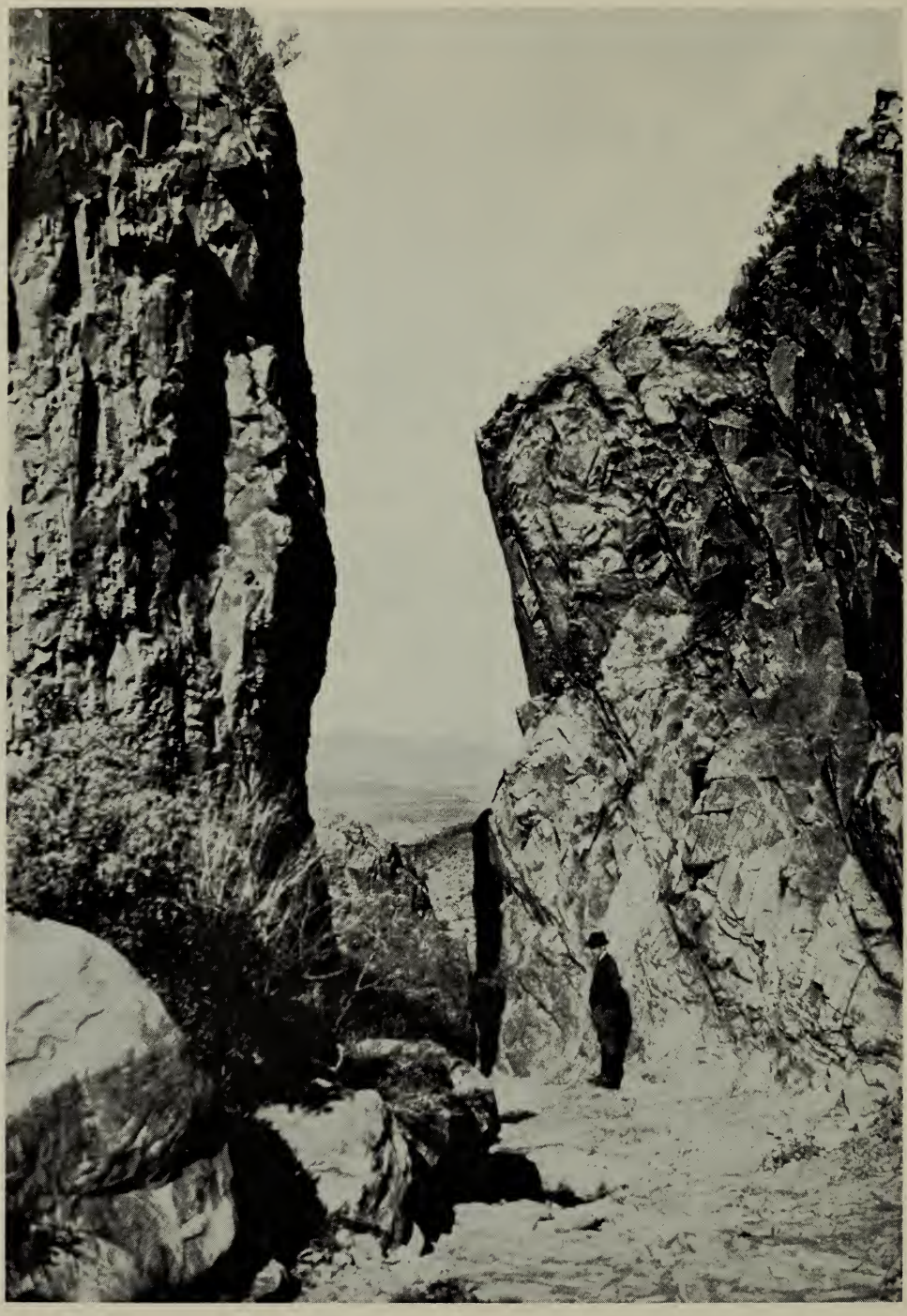


FIG. 126. The Window, a narrow canyon in the gap between Ward Mountain and Vernon Bailey Peak. Note inclined jointing, which is toward the southeast.

Creek, at the south flank of Ward Mountain (Pl. II; K, 15), vertical beds in the Chisos Formation lie along the contact. Along the concave side of the pluton, at the divide between Green Gulch and the Basin, on the south side of the intrusion (Pl. II; L, 16), nearly horizontal beds in the Chisos Formation crop out within a few feet of the pluton without any evidence of contact metamorphism, and there is a small outcrop of unmetamorphosed Aguja Formation near the southwest end of Vernon Bailey Peak (Pl. II; L, 15). Boquillas strata, showing contact metamorphic effects, are arched concordantly over the pluton along the northeast and east sides of Ward Mountain (Pl. II; L–M, 15–16) and in Laguna (Pl. II; K, 15). In Laguna, the Boquillas outcrops occur as high as 7,000 feet, or several thousand feet above the normal altitude of these strata in areas surrounding the Chisos Mountains.

The rocks throughout the pluton are much alike. All samples that have been examined are quartz-rich with sodic amphibole and/or sodic pyroxene. Two rock types can be distinguished. The dominant one is riebeckite microgranite, with more than 75 percent SiO_2. A subordinate aegirine-augite microgranite, with 69 percent SiO_2, occurs near the Window (Pl. II; L–M, 15) and near the eastern end of Pulliam Peak (Pl. II; M, 16); its extent is outlined by dashed lines on the map (Pl. II). It contains a distinctive unidentified iron-rich silicate mineral that superficially resembles resin. All the rocks of the pluton probably came from the same magmatic source, but there are several intrusions in the crescent-shaped pluton.

Ward Mountain is domical and oval in plan; Vernon Bailey Peak is also domical but less round in plan. The Window (figs. 126 and 11) which separates the two mountains has been cut in closely jointed rocks; the joints being inclined toward the southeast parallel a mineral lineation. When the northwest flank of the pluton is viewed from high on Vernon Bailey Peak, it appears to have been emplaced diagonally upward toward the northwest.

The aspect of the pluton changes east of Vernon Bailey Peak; where it is much more jointed, weathering along large joint surfaces has produced columns, pinnacles, spires, and buttresses in the western part of Pulliam Peak, whose rough profile contrasts with the smooth profile of Vernon Bailey Peak and Ward Mountain. The saddle between Pulliam and Vernon Bailey Peaks is probably on the contact between two separate intrusions. The extreme eastern part of Pulliam Peak has a smoother profile, is more massive in appearance, and more nearly domical.

Tortuga Mountain.—A small stock of riebeckite granite forms Tortuga Mountain (Pl. II; H–J, 17) in the southern part of the Chisos Mountains and has pierced a slightly elongate dome about 2 miles long away from which Tertiary and Cretaceous strata as old as Aguja Formation dip at angles of 35°. A gabbro sill 150 feet thick intruded in the Aguja Formation was folded with the strata and crops out as a ring around the central part of the dome.

The Tortuga Mountain stock crops out in an irregular area only a few hundred yards in diameter. The highest parts of the outcrops are at about the projected level of the gabbro sill. The exposed rock varies greatly in texture and the highest part of the mass is porphyritic. Some of the marginal material is fine grained and resembles the paisanite of the Chisos Mountains Pluton. The rock in the core of the plug is composed of coarse crystals as much as 5 mm in diameter and is the coarsest siliceous igneous rock in the Park. A typical specimen of this rock is described in table 13 (loc. 58).

Blebs and irregular masses of pegmatite intrude the riebeckite granite and are the only ones known in siliceous igneous rocks in the Park. They contain alkali feldspar crystals as well as smoky quartz as much as 2 inches long, in part subhedral, and fluorite. Graphic granite and crystals of alkali feldspar and smoky quartz occur in a prospect pit in a large vug or miarolitic cavity in the southern part of the stock. Fluorite was deposited in fractures that cut the peg-

matite and on corroded crystals of quartz and feldspar in the cavity. A later generation of quartz, in small vitreous crystals, encrusts part of the mass. Molybdenite has been reported but was not seen by the writers.

The Tortuga Mountain stock is the only mass of siliceous igneous rock in the Park that appears not to have crystallized under fairly shallow hypabyssal conditions. It intruded the Aguja Formation, which is overlain by 200 feet of strata tentatively identified as Canoe Formation and approximately 3,000 feet of Chisos Formation. The Chisos Formation is overlain by more than 900 feet of Tertiary lava (Pl. X, sec. 44) on the South Rim 3 miles north of Tortuga Mountain (Pl. II; K, 16–17). Probably the minimum thickness of the cover during the crystallization of the Tortuga Mountain riebeckite granite was about 4,000 to 4,500 feet.

Syenodiorite-Syenogabbro and Related Rocks

Dominguez Mountain.—Dominguez Mountain (Pl. II; G, 16) in the southern part of the Park, is a conical peak (fig. 146) which projects about 1,700 feet above the surrounding area. The mountain is a composite intrusive consisting of three distinctive rock bodies that intruded Tertiary pyroclastic rocks and lavas. Along most of the north, east, and south sides of the mountain, the beds in contact with the intrusion are metamorphosed to a dense material (hornfels) that is resistant to erosion and has formed a rim 100 to 500 yards wide. The rocks in contact with the intrusion are probably Chisos Formation, but along the southern flank of the mountain, the rock is more like the Wasp Spring Member of the South Rim Formation. Bedded rocks generally dip away from the intrusion on all sides and, in places, beds are almost vertical at the contact. Along the eastern flank of the mountain, the general dip is modified by the Backbone Ridge intrusion (Pl. II; G, 17) and the Cow Heaven anticline (Pl. II; D–G, 17–18).

The largest of the three rock bodies in the composite mass ranges in texture and composition from very coarse-grained gabbro to much finer grained porphyritic rock containing quartz and considerably less plagioclase. Except for variations in grain size, all of the rock types are superficially similar. They are dark gray when fresh and light gray when weathered; they tend to weather spheroidally and yield finely granular detritus.

Composition of the rock ranges from olivine syenodiorite through hornblende-augite syenite with considerable plagioclase to quartz-hornblende syenite; possibly some granite is present. The rock body appears to be roughly zoned vertically and possibly also horizontally, but no sharp boundaries have been observed between adjacent parts. In large exposures, it is seen that the general upward change from coarse-grained to fine-grained rock is gradational.

The coarsest grained rock is a dark-gray to almost black olivine syenodiorite, well exposed in the canyon that crosses the western side of the intrusion. For analysis, see item no. 73, tables 14 and 16 (pp. 245 and 270). The rock is composed mainly of subhedral to anhedral feldspar crystals as much as 10 x 15 mm, with finer grained interstitial material. The larger crystals are andesine (An_{44}) zoned to more sodic andesine and partly rimmed with alkali feldspar which is in part perthitic. The interstitial material is mainly irregular grains of alkali feldspar (anorthoclase(?), 2V moderate) with pale-violet augite, olivine, red-brown biotite, ore grains, apatite, and brown hornblende. The mafic and accessory minerals are more abundant in the interstitial material but also form as inclusions in the feldspars. Poikilitic pale-violet augite, including ore grains and olivine (or its reaction products), forms as anhedral crystals as much as 2 x 2.5 mm in diameter. Olivine ($2V = 90° \pm$) forms crystals as

much as 1 x 1.5 mm in diameter that are only slightly altered to serpentine, but olivine more commonly forms aggregates with ore grains and red-brown biotite. Green to colorless mica borders a slender veinlike inclusion of olivine in feldspar. Apatite, in stubby prisms up to 0.4 x 0.4 mm, is included in all other minerals. There is a trace of brown hornblende in the aggregates and as discrete grains. Modes from two thin sections are: andesine, 48 and 46 percent; alkali feldspar, 32 and 36 percent; augite, 5 and 8 percent; hornblende, trace; olivine, 6 and 5 percent; biotite, 4 and 2 percent; ores, 4 and 3 percent; and apatite, 2 and 1 percent. Another analyzed sample of very coarse rock (item no. 64, tables 14 and 16) from slightly higher in the mass has plagioclase (An_{38}) crystals as much as 2 cm long surrounded by a matrix containing more biotite and hornblende, no olivine, and a trace of quartz. The relations of ore grains, augite, and biotite in this rock suggest that olivine was an original constituent and was converted through reaction to other minerals.

Most of the rock samples collected from higher in the mass are syenite composed of plagioclase (An_{38-40}) and alkali feldspar (commonly perthitic), along with augite, ore grains, hornblende, biotite, apatite, and zircon. A trace of quartz occurs in one sample from the top of the mountain. The syenite is slightly porphyritic with a xenomorphic-granular-seriate texture and grains as much as 1 mm in diameter. The hornblende is a reaction product from augite. The quantity of augite in the sample from the top of the mountain is negligible; the abundant hornblende is slightly replaced by or changed to blue sodic amphibole (riebeckite).

One medium-grained rock, collected about 600 feet below the top of the mountain, is composed of about equal quantities of anorthoclase and perthite, with augite (partly altered to hornblende), fayalitic olivine, ore grains, zircon, apatite, and a trace of interstitial quartz. The texture is xenomorphic-granular-seriate.

The second rock body in the Dominguez Mountain composite intrusive mass is trachyandesite porphyry. Throughout the Park there are many small rock masses with similar appearance. There is a large, continuous exposure of trachyandesite porphyry along the upper western flank of Dominguez Mountain (Pl. II); a smaller dikelike mass of the same rock forms the northwestern border of the intrusion. The larger mass has two sets of very regular joints, one nearly horizontal, the other vertical. The rock spalls along joints and the west-facing exposure of the larger mass appears layered from a distance. Contacts near the western end of the larger mass and contacts of the dikelike mass are nearly vertical. The available evidence indicates that both trachyandesite porphyry bodies cut the syenogabbro.

The analyzed specimen of andesite porphyry (item no. 67, tables 14 and 16) consists of a dense xenomorphic-granular groundmass of alkali feldspar, plagioclase, augite, and ore grains with an average size of about 0.05 mm studded with plagioclase (An_{42-44}) phenocrysts up to 5 x 12 mm. A few larger aggregates of ore grains up to 2.5 x 2.5 mm appear to be derived from the alteration of mafic silicate minerals. The selvage of the rock from this locality is not noticeably porphyritic.

Specimens from other parts of this body differ only slightly from the analyzed sample. One specimen contains a few larger crystals of augite and has lath-shaped feldspar in the groundmass. Another specimen contains generally smaller plagioclase phenocrysts with composition An_{52} and about one-half percent biotite. The groundmass of another specimen is coarser and contains skeletal crystals of mafic minerals.

The third distinctive rock body in the Dominguez Mountain intrusive mass is exposed in an area about a mile long and as much as 1,000 feet wide along the extreme western flank. The rock is a white to lavender porphyritic leucorhyolite. Feldspar phenocrysts, as much as 4 mm long, are anorthoclase ($2V = 40° \pm$, $nZ = 1.528$) intergrown with albite. The matrix is a dense hypautomorphic-granular to fine micro-

graphic aggregate of quartz and alkali feldspar with quartz poikilitic to feldspar, a small amount of altered mafic minerals, and a trace of zircon. A trace of secondary fluorite occurs in vugs.

The canyon that crosses the western side of the intrusion follows the contact between this body and the syenodiorite-syenogabbro for some distance. The porphyritic leucorhyolite appears to cut the syenodiorite and is considered to be the youngest of the three rock bodies in the Dominguez Mountain composite mass.

Dike Swarm

Dikes in the swarm associated with Dominguez Mountain cut all three types of rocks in the composite intrusion and extend outward in all directions from the mountain. The dikes are larger, more numerous, and extend farther from the intrusive mass on the southwest side. Most dikes shown on Plate II have been examined, but those crossing the lava of Punta de la Sierra (Pl. II; E–F, 15–16) and a few others were mapped from aerial photographs. The dikes extending southwestward from Punta de la Sierra to the Rio Grande are considered to be part of the swarm because they are aligned with and closely resemble dikes nearer Dominguez Mountain composition. Additional thin dikes probably are exposed only in the arroyos.

The dikes are from a few inches to 30 feet thick. Most of the dikes are simple; a few dikes are branched or have offshoots. Groups of parallel composite dikes are well exposed at two places in the west wall of the canyon southwest of Dominguez Mountain. Six dikes ranging from 10 to 18 feet thick crop out in a distance of 100 feet at the first locality. Except for one narrow exposure of lava separating two of the dikes, the trachyte, alkali quartz trachyte, and olivine trachybasalt dikes of this group are in contact with each other and form a single unit. The second group of dikes, similar in size, arrangement, and composition to the first group, crops out about 200 yards downstream from the first locality.

Many of the dikes are deeply weathered. Field examination gives the impression that only a few rock types occur but a surprising range in composition is disclosed by examination of thin sections. The freshest rocks are basaltic and range from dark green to black. Most of the rocks are porphyritic; some are strikingly so, with abundant plagioclase phenocrysts as much as 15 x 20 mm in diameter. Some of the dike rocks are composed almost entirely of small phenocrysts as much as 2 x 2 mm; hand specimens of the rock appear to be fine or medium grained and equigranular because the groundmass is sparse. A very few of the dike rocks are nonporphyritic equigranular or seriate fine grained to aphanitic. Nonporphyritic border selvages occur in some of the porphyritic dikes.

Descriptions of the predominant rock types recognized in the Dominguez dike swarm follow.

Microgranite.—A dike of microgranite about 2 feet thick cuts the eastern part of the Dominguez Mountain composite intrusion. The microgranite is an xenomorphic-granular aggregate of feldspar, quartz, and weathered mafic minerals with a trace of zircon. Except for a few larger crystals of feldspar, the rock is nearly equigranular, with an average grain size of about 0.6 mm. Most of the feldspar is finely perthitic. A few of the feldspar crystals are subhedral; quartz is anhedral and interstitial.

Approximate mode: potassium feldspar, 69 percent; quartz, 29 percent; weathered mafic minerals and ore, 2 percent.

Biotite microgranite.—A dike rock from the eastern part of Dominguez Mountain is biotite microgranite. The rock is a xenomorphic-granular aggregate of alkali feldspar, albite, quartz, biotite, and a little perthite with traces of fluorite, ore grains, zircon, and apatite. The average grain size of the major constituents is 0.2 to 0.3 mm.

Feldspar is mainly slightly perthitic

alkali feldspar but there are a few discrete grains of plagioclase (An_{10}). Quartz forms interstitial material and is poikilitic to feldspar; there is a slight development of micrographic texture. Biotite, mostly weathered, occurs as irregular shreds poikilitic to quartz and with pleochroic halos around zircon.

Approximate mode: weathered alkali feldspar including albite, 71 percent; quartz, 21 percent; biotite, 8 percent; and traces of fluorite, zircon, ore minerals, and apatite. The chemical analysis of this sample is presented as item no. b, table 16.

Leucorhyolite.—A leucorhyolite dike about 2 feet thick cuts syenogabbro in the east wall of the canyon crossing the western part of the Dominguez Mountain intrusion. The leucorhyolite consists of abundant phenocrysts of perthitic alkali feldspar embedded in a light-gray, aphanitic, xenomorphic-granular to granophyric groundmass of perthitic alkali feldspar and quartz. Slightly more than half the rock is groundmass. Average size of the phenocrysts is 0.7 mm; average grain size of the groundmass is 0.1 mm. The quartz content of the rock is 15 percent; mafic minerals are rare and there are a few minute crystals of zircon.

The chemical analysis of the sample from this dike is item no. c, table 16.

Rhyolite.—A 20-foot-thick dike of rhyolite cuts both syenogabbro and a mafic dike near the southeast flank of Dominguez Mountain. It is composed of perthitic feldspar phenocrysts, with maximum size 3 x 4 mm, in a light-gray, hypautomorphic-granular groundmass with an average grain size of 0.1 mm. About 10 percent of the rock is quartz that occurs interstitially in the groundmass. Originally there were some mafic minerals in the groundmass, but only the ore grains remain unaltered.

Quartz latite.—Several of the dikes are composed of dark-green to greenish-gray porphyritic rock that is difficult to distinguish in the field from the porphyritic basaltic rock of other dikes in the swarm. The rock contains plagioclase (An_{38-42}) phenocrysts up to 5 x 7 mm and a few smaller augite phenocrysts in a groundmass consisting mainly of alkali feldspar, 5 to 8 percent interstitial quartz, and a few percent clinopyroxene. Apatite and metallic grains are accessory minerals. The average grain size of the xenomorphic-granular to hypautomorphic-granular groundmass is 0.15 mm. About 30 percent of the total feldspar content of the rock is plagioclase.

Quartz syenite.—An 8-foot-thick dike of quartz syenite is exposed in the south wall of the canyon west of Dominguez Mountain. The gray, medium-grained rock has xenomorphic-granular seriate texture. The largest feldspar crystals are 2 x 3 mm.

Approximate mode: potassium feldspar, 50 percent; andesine(?), 25 percent; quartz, 10 percent; augite and hornblende, 10 percent; ore minerals, 5 percent.

Hornblende-quartz syenite.—A dike of hornblende-quartz syenite that cuts the composite intrusive mass was sampled east of Dominguez Mountain. Except for rare feldspar phenocrysts up to 3 x 5 mm, the rock has xenomorphic-granular texture seriate from 0.01 to 0.02 mm to about 1 x 1 mm. Andesine (An_{38}) is the predominant mineral; brown hornblende and quartz are present in substantial amounts. Other minerals include biotite, gray augite, zircon, apatite, and ore grains. The brown hornblende forms ragged, irregular grains that are partly zoned or fringed with blue-green amphibole. Quartz is interstitial.

The chemical analysis of this sample is item no. d, table 16.

Augite-hornblende-quartz syenite.—A dike of augite-hornblende-quartz syenite near the center of the composite intrusion was sampled at a point south of the highest peak of Dominguez Mountain. The rock has xenomorphic-granular seriate texture with a relatively large number of large feldspar crystals up to 4 x 5 mm. Perthitic potassium feldspar with oligoclase ($An_{20\pm}$) is the predominant mineral. Other minerals include andesine (An_{40}) rimmed with orthoclase ($2V = 60°$), about 1 percent; gray-green augite partly altered to brown hornblende; quartz, both as discrete grains and as interstitial material, 3

to 4 percent; ore grains; apatite; and rare grains of zircon.

Quartz trachyte.—Many of the lighter colored dike rocks, especially those close to the mountain, are trachytic or felsitic; most of them are quartz trachyte. All are weathered. Common colors are light gray, pinkish gray, yellow, reddish brown, and grayish green. The rocks are commonly slightly porphyritic to porphyritic with phenocrysts or glomerocrysts of potassium feldspar in a groundmass that is either cryptocrystalline or has hypautomorphic-granular to subtrachytic texture. The phenocrysts are less than 1 mm to 5 mm in diameter; size of the groundmass minerals is less than 0.1 mm. The quartz trachytes are assemblages of potassium feldspar (as phenocrysts, as glomerocrysts, groundmass aggregates), quartz, pyroxene, and amphibole. Mafic minerals in most of the samples are restricted to the groundmass and are now represented by brown secondary products with the pattern of sodic ferromagnesian minerals; rare weathered microphenocrysts of clinopyroxene occur in a few of the rocks. Quartz forms interstitial material in some samples and discrete grains in others; the quartz content of examined samples, with few exceptions, is from 3 to 8 percent. Ore grains, apparently in part secondary, and zircon occur in some of the samples.

Porphyritic syenite.—Porphyritic syenite dikes were sampled at two localities. One dike cuts the Dominguez composite intrusive near its southern margin, the other cuts the Chisos Formation west of the composite mass. The rock consists of abundant armored phenocrysts of andesine (An_{43}) in a dark-green, hypautomorphic-granular groundmass. Phenocrysts are as much as 7 x 10 mm in diameter; average grains in the groundmass average 0.5 mm.

Slightly elongate, simple, untwinned crystals of anorthoclase (2V moderate) as much as 0.6 mm long constitute the bulk of the rock. A few of the anorthoclase crystals have plagioclase cores; many crystals enclose bundles of aegirine-augite needles that produce a Schiller effect. Aegirine-augite needles grade upward in size to slender prismatic crystals that are partly poikilitic and partly interstitial. The few gray augite crystals, as much as 2 mm long, are very slightly zoned to green sodic pyroxene. Stubby prisms of apatite occur. Abundant magnetite-ilmenite grains as much as 0.4 mm in diameter are enclosed in all other minerals except apatite. Interstices between faces of the feldspar crystals are filled with a brownish-red material that contains small crystals of aegirine and the brown sodic amphibole arfvedsonite(?). At least part of the brownish interstitial material was probably derived from the amphibole.

An estimated mode is: anorthoclase, 70 percent; plagioclase, 5 percent; ore, 1 percent; augite, aegirine-augite, arfvedsonite, and weathering products, 24 percent.

The dike selvage is a nonporphyritic, dense aggregate of alkali feldspar laths with rare phenocrysts of altered plagioclase, rare grains of altered mafic minerals, and ore grains.

Fayalite syenite.—A dike of fayalite syenite cuts the metasedimentary rim north of Dominguez Mountain. The rock has xenomorphic-granular-seriate texture with a grain size of 0.02 to 2.5 mm. The largest crystals of the mafic minerals are only slightly smaller than the feldspar crystals. Anorthoclase and perthitic alkali feldspar occur in about equal amounts. Other minerals include gray-green augite ($2V = 55° \pm$) in part altered to brown hornblende ($Z \wedge c = 17°$), fayalitic olivine (–) ($2V = 60° \pm$), ore grains, a few irregular grains of zircon up to 0.7 mm, minute needles of apatite, and a trace of interstitial quartz. Some augite crystals are completely enclosed by the brown hornblende. The fayalitic olivine has unusually distinct parting parallel to (010). Part of the fayalitic olivine and augite and most of the hornblende and ore grains occur in aggregates; only a small part of the hornblende and ores occurs as discrete grains.

The chemical analysis of a sample from this dike is item no. 3, table 16.

Syenite.—A syenite dike near the top of

the intrusion is composed of a xenomorphic-granular aggregate of irregular to anhedral laths of perthite, rare crystals of plagioclase, augite, ore grains, and quartz with a trace of fluorite and rare zircon crystals. Perthite laths range up to 4 mm in length and most of the laths exhibit Carlsbad twinning. Plagioclase crystals show albite twinning. Augite occurs as slightly pleochroic, green to grayish-green, irregular prisms that commonly range up to 0.3 x 0.4 mm and rarely attain a length as great as 0.9. Ore grains are about the same size as the pyroxene crystals; the ore grains and pyroxene crystals commonly occur together in prominent aggregates.

Approximate mode: feldspar, 94 percent; augite, 3 percent; ore, 2 percent; quartz, 1 percent; zircon, tr.; and fluorite, tr. The chemical analysis of this rock is item no. f, table 16.

Trachyte.—The rocks of several sampled dikes in the swarm are normal trachyte. They are porphyritic with chalky feldspar phenocrysts and glomerocrysts as much as 5 x 6 mm in diameter embedded in a weathered dark grayish-green groundmass composed of a dense aggregate of alkali feldspar and brownish secondary materials with the pattern of pyroxene or amphibole. Apatite and ore grains occur in all specimens and a trace of quartz occurs in some specimens. A few small weathered phenocrysts of greenish clinopyroxene as much as 0.8 mm in length occur in places. Deeply weathered phenocrysts of both potassium feldspar and oligoclase ($An_{24?}$) are common. The amount of potassium feldspar greatly exceeds plagioclase. The groundmass of one sample includes laths of potassium feldspar as much as 0.8 mm in length, and weathered plagioclase is An_{35}.

A few dikes less than a foot thick that cut the main intrusive mass of Dominguez Mountain are a fine-grained rock with a salt-and-pepper texture. The average grain size is 0.5 mm. One of these dikes is a xenomorphic-granular aggregate of albite (An_8), potassium feldspar, about 10 percent weathered interstitial mafic material, a trace of quartz, and rare minute crystals of apatite and zircon.

The analysis of one of the trachyte samples is item no. 68, table 16.

Augite-hornblende syenite.—A dike of augite-hornblende syenite was sampled near the southern margin of Dominguez Mountain. It consists of sporadic plagioclase (An_{38}) phenocrysts mantled with alkali feldspar in a xenomorphic-granular-seriate groundmass. The larger crystals in the groundmass interlock, but granular interstitital material is relatively large. The phenocrysts are as much as 4 x 6 mm in diameter; the groundmass minerals are 0.02 to 0.5 x 0.5 mm. Most of the rock is alkali feldspar, some of which is perthite, and plagioclase; the plagioclase-alkali feldspar ratio is 1:7 to 1:8. The rock also contains gray-green augite ($Z \wedge c = 54°$), some brown hornblende ($Z \wedge c = 20°$) associated with the augite, ore grains, and apatite needles and prisms. A trace of biotite rims the ore grains.

The chemical analysis is item no. 72, table 16.

Syenogabbro.—A rock mass about 80 feet thick is exposed for about 400 feet in the canyon east of Dominguez Mountain. This is petrographically similar to syenogabbro and may be an offshoot from the Dominguez intrusion but is herein considered part of the dike swarm.

The rock is an alkali gabbro or syenogabbro and closely resembles the very coarse-grained part of the rock in Dominguez Mountain. It is composed of labradorite (An_{54}) crystals up to 5 x 7 mm, subhedral to anhedral crystals of augite up to 1 x 2 mm and poikilitic to plagioclase, ore grains, and a groundmass composed of alkali feldspar laths and grains. The groundmass, with an average size of 0.5 mm, makes up only a small part and contains abundant alteration products. Apatite is a prominent accessory mineral. Calcite commonly replaces plagioclase.

Olivine trachybasalt.—Many of the dark-colored dike rocks, including the freshest rocks in the dike swarm, are olivine trachybasalt. Most are porphyritic;

some are strikingly porphyritic with abundant plagioclase phenocrysts as much as 15 x 20 mm in diameter; a few are either nonporphyritic equigranular or seriate and fine grained to aphanitic. Nonporphyritic selvages border some of the porphyritic dikes.

These dike rocks are assemblages of plagioclase and alkali feldspar with augite, olivine, and ore minerals. Apatite is a common accessory mineral. Some contain analcite and some a trace of biotite. Olivine probably was an original constituent of all of them, but many preserve only its alteration products.

The plagioclase phenocrysts range from An_{59} to An_{49}. The plagioclase of some samples is zoned from labradorite to sodic andesine. The composition of the plagioclase phenocrysts differs from the composition of the groundmass plagioclase. The alkali feldspar probably is anorthoclase; in some specimens Nz = 1.528. There is a considerable range in the proportions of plagioclase and alkali feldspar. The exact proportions have not been determined because the examined specimens are not suitable for precise modal measurements; inspection of many thin sections indicates that the rocks are trachybasalt, although the feldspar ratio varies considerably.

The chemical analysis of a trachybasalt is item no. 75, table 13.

Basalt.—Two dikes of nonporphyritic basalt that apparently do not contain olivine were sampled. One is a 10-foot-thick dike near the southern margin of the Dominguez Mountain intrusion; the other is a 2-foot-thick dike exposed in the canyon east of the mountain. Both of the dikes are deeply weathered. The basalt consists of aggregates of plagioclase (An_{50}) laths about 0.2 mm long in a turbid, dense matrix containing ore grains and secondary materials that probably were derived from augite.

Olivine-Quartz Rocks

McKinney Hills (Pl. II; N–Q, 22–24) and Grapevine Hills (Pl. II; P–Q, 19), both in the Park, and the Rosillos Mountains (Pl. II; T–S, 18–19), immediately north of the mapped area, are laccolithic intrusions that appear to be petrographically related. The principal rock type of the McKinney and Rosillos intrusions is augite-hornblende granite or microgranite with variable amounts of iron-rich olivine that in some samples forms as much as 5 percent of the rock. The Grapevine Hills mass is a sodic granite or microgranite slightly different from the other two bodies (loc. no. 10, table 13) with dark-gray, iron-rich olivine (fayalite) rock only near the northeast flank. Weathering has obscured the relation of the iron-rich olivine rock to the other rocks. Modes of the olivine-quartz rock from the three intrusions are given in table 11.

McKinney Hills.—The McKinney Hills are an irregular, partly discordant, "pine tree"-shaped laccolith about 10 miles northeast of the Chisos Mountains (Pl. II; N–Q, 22–24). The hills are flanked by the Sierra del Carmen on the east and the Tornillo Creek valley on the west. The exposed mass is as much as 6 miles long and 3 miles wide and has been tilted by faulting and deeply eroded. The base of the intrusion is exposed almost continuously along the truncated eastern flank and is about 50 feet above the base of the Pen Formation which dips southwestward beneath it at angles of 10° to 12° in the north and as steeply as 35° in the south. At Roys Peak (Pl. II; O, 23) the intrusion is about 950 feet thick. The upper contact crosscuts formations both above and below the Pen (San Vicente Member to Aguja). The formations in contact with the upper surface of the mass dip as steeply as 35°, and some of the locally discordant contacts are steeper (Pl. II).

A pendant of sandstone of the Aguja Formation about 3 miles long and half a mile wide is preserved along a northwest-trending fault that extends nearly across the north-central part of the intrusion (Pl.

TABLE 11. *Modes (in percent) of fayalite-quartz rocks.*

	Grapevine Hills	McKinney Hills	Rosillos Mountains
Quartz	12.5	11.0	4.5
Alkali feldspar; in part anorthoclase	75.6	78.0	59.5
Plagioclase	0.4	tr	20.8
Composition of plagioclase	An_{11}	An_{28}	An_{17}
Augite }	5.5	4.0	3.8
Aegirine-augite }		....	....
Hornblende	....	2.0	6.6
Olivine and serpentine	3.3	3.0	2.2
Biotite	tr	....	tr
Ore minerals	2.7	2.0	2.6
Zircon	tr	....	....
Apatite	tr	tr	tr
Totals	100.4	102.0	100.0

II; O–P, 23), and another small Aguja remnant caps a hill in the central part of the mass (Pl. II; P, 23). Along the southwest flank, thin discordant sections of the San Vicente and Pen Formations are the cap rock. Thermal contact metamorphic effects in the underlying Pen clay are minor. The overlying sandstone layers are also generally unaffected, but shaly rocks are much altered. Most of the calcareous rocks (San Vicente) are mottled and contain numerous buckshotlike porphyroblasts. The clays, mainly in the Pen but locally in the Aguja, were changed to hard, dense, siliceous hornfels that the aborigines used for arrow or dart points and other tools. Hornfelsed clay is exposed at Banta Shut-In (fig. 46) where Tornillo Creek has carved a narrow gorge in the southwest flank of the intrusion (Pl. II; N, 23).

Rock types in the McKinney Hills intrusion vary greatly. Most abundant rock

TABLE 12. *Modes (in percent) of fayalite microgranite, McKinney Hills.*

	1	2	3	4	5
Quartz	11.0	11.0	5.0	12.0	15.0
Alkali feldspar	68.0	78.0	77.0	65.0	82.0
Plagioclase	2.0	tr	....	6.0	....
Augite	6.0	4.0	5.0	4.0	
Aegirine-augite	....	....		....	3.0
Hornblende	3.0	?	tr	3.0	....
Riebeckite	....	....	....	....	....
Biotite	....	....	....	....	....
Fayalite	7.0	3.0	9.0	6.0	....
Ore minerals	3.0	2.0	4.0	4.0	tr
Micropegmatite	tr	tr	tr	tr	....
Fluorite	tr	....	tr	....	....
Apatite	tr	tr	tr	....	....
Zircon	tr	....	tr	....	tr
Rutile	....	tr?	....	....	....
Totals	100.0	98.0	100.0	100.0	100.0

1. Main rock immediately northeast of Roys Peak.
2. Main rock southwest of Roys Peak.
3. Main rock northwest of Roys Peak.
4. Main rock 2 miles north of Roys Peak.
5. Three small isolated masses half a mile north of McKinney Hills uplift.

is fayalite microgranite, dark gray and fine grained with feldspar crystals up to 2 mm. Microscopic examination indicates about 12 percent quartz, 68 percent alkali feldspar, a little sodic plagioclase, 6 percent augite, part of which is slightly zoned to sodic pyroxene and some of which is altered to hornblende, 3 to 7 percent fayalite, represented partly by green alteration products, a few percent of ore grains, some interstitial micropegmatite and fluorite, apatite, and zircon as minor accessories. Mode of the McKinney Hills fayalite microgranite is shown in table 12.

The marginal rocks of the intrusion are mostly fine grained but the rock is not olivine-bearing and is a quartz microgranite. In the samples studied, quartz is sparse and the weathered mafic minerals appear to be sodic. Similar rocks occur on the northeastern flank of the intrusion (Pl. II; Q, 24) and at the south end (Pl. II; N, 23). At other places along the east and northeast flanks is a tabular body of leucorhyolite about 15 feet thick that seems to be younger than the main McKinney rock mass. The leucorhyolite is chiefly alkali feldspar with about 15 percent quartz and traces of altered mafic minerals. A sample of one rock has obscure pyroclastic texture. Dikes of leucorhyolite cut the main intrusion and the country rock close to its margins.

TABLE 13.—Description of igneous rocks, Big Bend National Park.

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
	GRANITE-RHYOLITE (Loc. Nos. 1–120)	
R, 13, northwest part of map Loc. 1 F. S. No. 87B	Laccolith extending beyond map area	*Sodic rhyolite.* Light gray hypautomorphic-granular aggregate of alkali feldspar, weathered sodic ferromagnesian minerals, and interstitial quartz; average grain size 0.2 mm. Microphenocrysts of anorthoclase ($2V = 50°$) 0.4×0.4 mm are rare. Zircon, apatite, and micropegmatite occur as traces.
O, 14, south flank of Slickrock Mountain Loc. 2 F. S. No. 813	Sill(?), 20 feet thick, exposed 0.2 mile	*Spherulitic rhyolite.* Light gray weathered aggregate of alkali feldspar spherulites (average 1 mm in diameter) with about 15% interstitial quartz, about 8% completely altered mafic minerals, and rare alkali feldspar microphenocrysts.
O, 14, 3.5 miles northeast of Burro Mesa Loc. 3 F. S. Nos. 186, 187ABC, 485AB	Tabular, 200 feet thick, domed, irregularly exposed 1.0×1.5 miles; columnar jointing in vertical exposures	*Microgranite.* Gray hypautomorphic-granular seriate rock from 0.04 to 0.8 mm with rare feldspar phenocrysts. Anorthoclase in simple euhedral crystals ($2V = 45° \pm$) makes up the bulk of the rock. Quartz (10%) is in discrete grains and interstitial and marginal micropegmatite; mafic minerals are altered to limonitic material (15%); there is a trace of zircon.
O, 14, 1.5 miles south of Croton Peak Loc. 4 F. S. No. 185	Sill, 15 feet thick, exposed 0.4 mile at flank of hill	*Rhyolite.* White weathered rock, slightly micrographic; there are very few mafic minerals.
P, 14–15, Croton Peak Loc. 5 F. S. Nos. 190, 702ABC	Sheetlike, probably continuous with Paint Gap Hills mass and possibly includes separate plug near southwest end	*Alkalic microgranite.* Light gray xenomorphic-granular seriate rock, average grain size 0.4 mm, with very rare feldspar phenocrysts 1×3 mm and a small quantity of interstitial micropegmatite. Laths and tablets of sanidine-anorthoclase, 82%; quartz, 9%; ore grains, 9%; zircon and fluorite, tr. Mafic minerals are completely altered.
P-Q, 16, Paint Gap Hills and extensions in P, 17 Loc. 6 F. S. Nos. 91, 228, 501B, 502; 246 (not studied)	Sheetlike, probably continuous with Croton Peak mass	*Alkalic microgranite.* Light gray xenomorphic-granular to hypautomorphic-granular aggregate of weathered feldspar, average 0.5 mm, weathered mafic minerals and about 8% quartz, average 0.2 mm. Feldspar includes potash feldspar and sodic oligoclase(?). Some specimens lack mafic minerals. There is a slight development of interstitial micropegmatite.
P, 17, 1 mile east of Paint Gap Hills Loc. 7 F. S. No. 500	Sill, 3 feet thick, exposed in creek bed	*Rhyolite.* Brownish-gray dense felty partly spherulitic aggregate of alkali feldspar and about 10% interstitial quartz with rare altered feldspar phenocrysts. Limonitic grains probably represent mafic minerals. Minute dustlike inclusions are abundant.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
O, 17, 1 mile north of Government Spring laccolith Loc. 8 F. S. No. 50B	Sill, 30 feet thick, exposed 0.9 mile; highly developed columnar jointing	*Granophyre.* White, weathered porphyritic rock with orthoclase(?) phenocrysts up to 2 mm in a finely granophyric groundmass and traces of mafic minerals, zircon, and fluorite.
O, 19, Lone Mountain Loc. 9 F. S. Nos. 54, 673A	Tabular, slightly discordant, 40 feet thick	*Alkalic microgranite.* Light gray hypautomorphic-granular aggregate of weathered alkali feldspar laths, average 0.4 mm, with 9% interstitial quartz. Limonite forms and spongy aggregates after mafic minerals and ore grains. Rare alkali feldspar phenocrysts are up to 6 mm.
P-Q, 19, Grapevine Hills Loc. 10 F. S. No. 58D	Laccolith, 2 × 2 miles	*Fayalite granite.* Bluish-gray, fine-grained hypautomorphic-granular rock with euhedral to anhedral tablets of anorthoclase to 0.7 × 1.8 mm (some armored with orthoclase), rare discrete grains of oligoclase (An_{11}), augite zoned to sodic pyroxene to 0.3 × 0.7 mm, fayalite mostly serpentinized, ore grains, biotite, zircon, and fluorite in a fine minor interstitial matrix of quartz and micropegmatite. There is a slight development of perthitic feldspar in rare crystals to 2 × 4 mm. Quartz and micropegmatite, 13%; alkali feldspar, 75%; oligoclase, 1%; pyroxene, 5%; fayalite and serpentine, 3%; ore minerals, 3%; biotite, fluorite, zircon, tr.
P-Q, 19, Grapevine Hills Loc. 11 F. S. No. 58B	Laccolithic intrusion	*Microgranite.* Like Loc. 10 except there is very little micropegmatite and no fayalite.
Q, 19, north flank of Grapevine Hills Loc. 12 F. S. No. 333	Dike, 8 feet thick, exposed 0.2 mile	*Sodic rhyolite.* Greenish-gray, dense, xenomorphic-granular aggregate of alkali feldspar and quartz with average grain size 0.08 mm, numerous needles of aegirine-augite(?) up to 0.2 mm, rare minute grains of brown amphibole and rare phenocrysts of aegirine-augite to 1 mm and weathered alkali feldspar to 2 × 2 mm. Quartz is poikilitic to feldspar and aegirine-augite.
S, 18–19, south flank of Rosillos Mountains, north boundary of map Loc. 13	Rosillos Mountains laccolith	*Fayalite microgranite.* Not sampled.
S, 20, southeast flank of Rosillos Mountains, north boundary of map Loc. 14 F. S. No. 798A	Rosillos Mountains laccolith	*Fayalite microgranite* (quartz poor). Fine-grained, xenomorphic-granular aggregate of quartz, anorthoclase, untwinned oligoclase, augite, altered fayalite, ore grains, and apatite.

S, 20, southeast flank of Rosillos Mountains, north boundary of map Loc. 15 F. S. No. 798B	Rosillos Mountains laccolith; bands and irregular masses 3 to 15 feet thick in F. S. No. 798A (Loc. 14)	*Leucomicrogranite.* Light gray—differs from F. S. 798A in that it contains very little augite and ore grains, no fayalite, and with a few larger armored plagioclase grains with calcic oligoclase cores.
N-Q, 22–23, between Tornillo Creek and McKinney Hills Loc. 16 F. S. Nos. 504ABC, 551, 906, 907, 908, 909, 891, 893, 894, 895	Twenty-odd dikes and sills, 1.5 to 6 feet thick, exposed about 0.1 mile	*Rhyolite.* Basaltic, trachytic, and rhyolitic masses, all weathered.
N-Q, 22–24, McKinney Hills laccolith (see pp. 248–253) Loc. 17	"Pine tree" laccolith, irregular 3 × 6 miles, faulted	See pages 186–188.
N, 23, Tornillo Creek, south end of McKinney Hills Loc. 18 F. S. No. 480	Sill-like, 4 feet thick, poorly exposed for 0.2 mile	*Leucorhyolite.* White, dense, felty aggregate of alkali feldspar with about 10% of quartz in discrete grains, average 0.1 mm, and rare microphenocrysts of alkali feldspar.
Q, 23, north flank of McKinney Hills Loc. 19 F. S. No. 910ABC	Four discordant dikelike masses along fault	*Spherulitic rhyolite.* Rock is composed of clumps and bundles of alkali feldspar laths, grains of quartz, and needles and grains of altered mafic minerals; texture is imperfect spherulitic.
P, 24, east flank of McKinney Hills Loc. 20 F. S. No. 708	Dike, 10 feet thick, exposed 0.2 mile	*Rhyolite.* Weathered hypautomorphic-granular aggregate of quadratic alkali feldspar (anorthoclase?) crystals, interstitial quartz, and a little micropegmatite.
G-H, 11–12, south of Kit Mountain Loc. 21 F. S. Nos. 282, 285(?), 651D, 794ABC, 795, 799E, 800, 924AB, 619, 633	Group of discordant masses from small plugs forming spines, to small tabular dikelike bodies all associated with rhyolitic extrusive rocks	*Riebeckite rhyolite.* Includes green to light green and gray similar but not identical rocks with riebeckite, sanidine, and quartz ranging from dense aphanites to microgranite, including some with granophyric texture. Aegirine is intergrown with riebeckite in discrete grains and sponges locally with plumes of riebeckite. Feldspar phenocrysts are rare. Some samples contain green sodic clinopyroxene.
H, 13, 1.5 miles southeast of Goat Mountain Loc. 22 F. S. Nos. 818, 900	Three plugs about 50 feet in diameter forming spires	*Rhyolite.* Light gray weathered mainly granophyric rock with a few percent of discrete quartz grains averaging 0.05 mm. Rare phenocrysts of perthitic feldspar are up to 1 × 2 mm; sparse mafic minerals are completely altered.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
H, 12, west flank of Goat Mountain Loc. 23 F. S. No. 923	Pluglike, forming spine 250 feet in diameter	*Rhyolite.* Not studied in detail.
J, 13, north side of Blue Creek Loc. 24 F. S. Nos. 145, 558, 608	Plug, oval shaped, 0.3 mile in diameter	*Porphyritic riebeckite rhyolite.* Light gray rock with a xenomorphic-granular seriate groundmass (up to 0.2 mm) of alkali feldspar, quartz, interstitial glass, sponges and plates of riebeckite and rare aegiritic pyroxene with anhedral to euhedral phenocrysts and glomerocrysts of quartz and sanidine ($2V = 20° \pm$) up to 5 mm.
K, 12, west flank of Burro Mesa Loc. 25 F. S. Nos. 602, 882ABD	Plug, 0.5 mile in diameter; a small isolated oval mass and one small dike	*Riebeckite rhyolite porphyry.* Gray rock with subhedral to euhedral quartz and opalescent sanidine-anorthoclase phenocrysts to 5 mm in a hypautomorphic-granular groundmass of equant quartz grains and alkali feldspar laths, average size 0.08 mm; quartz is poikilitic to feldspar. Riebeckite occurs in discrete grains and spongy aggregates to 0.6 mm; it is poikilitic to quartz and feldspar. Ore grains occur as inclusions in riebeckite.
K, 12, 1 mile west of mass, Loc. 25 Loc. 26 F. S. No. 605G	Plug, 0.2 mile in diameter	*Aegirine rhyolite porphyry.* Subhedral to euhedral phenocrysts of sanidine-anorthoclase and quartz to 5 mm, and needles of aegirine to 0.1 mm occur in a dense microcrystalline groundmass.
K, 12, 0.6 mile north of mass, Loc. 25 Loc. 27 F. S. Nos. 604, 882E	Irregular plug, 70 feet thick	*Riebeckite rhyolite porphyry.* Phenocrysts and glomerocysts of quartz and sanidine-anorthoclase up to 5 mm occur in a dense hypautomorphic-granular groundmass. Ragged riebeckite grains 0.1 mm are abundant. Ore grains are rare.
N, 12, near highway, north end of Burro Mesa Loc. 28 F. S. No. 739A	Tabular, essentially concordant in vertical beds, 20 to 50 feet thick, exposed 0.3 mile	*Porphyritic rhyolite.* Rock consists of a gray dense groundmass, average grain size 0.04 mm, of quartz poikilitic to minute laths of alkali feldspar and ore grains, with phenocrysts and glomerocrysts of andesine (An_{34}) up to 3.5×3.5 mm. Mafic minerals up to 1.5 mm are altered to calcite and ore grains. There is a trace of apatite.
L-M, 14; K, 15, southwest of Ward Mountain Loc. 29 F. S. Nos. 808A, 134AB	Dike, 20 feet thick, exposed intermittently 5 miles	*Rhyolite porphyry.* Weathered gray to white porphyritic rock with phenocrysts of microperthite and quartz to 4×8 mm. Groundmass is hypautomorphic-granular, slightly micrographic. Mafic minerals are rare and weathered.
K, 15, southwest of Ward Mountain Loc. 30	Dike, 10 feet thick, exposed 0.4 mile	*Quartz porphyry.* Not sampled.

L, 14, west of Ward Mountain Loc. 31 F. S. Nos. 808A, 397	Dike, 20 feet thick, exposed 4 miles	*Rhyolite porphyry*. Weathered. Euhedral and embayed quartz and weathered feldspar phenocrysts occur in an indistinct granophyric groundmass. Mafic minerals are weathered; there is a trace of fluorite.
K-L, 14, west of Ward Mountain Loc. 32 F. S. Nos. 808C, 147	Dike, 20 feet thick, exposed 1.5 miles	*Rhyolite porphyry*. Brown to greenish-gray weathered rock with euhedral and embayed quartz and sanidine phenocrysts up to 6 mm in a hypautomorphic-granular groundmass. Mafic minerals are weathered; there is a trace of fluorite.
K, 14, southwest of Ward Mountain Loc. 33 F. S. Nos. 63, 395, 611	Dike, 8 feet thick, exposed sporadically 0.5 mile	*Rhyolite porphyry*. Porphyritic rock with phenocrysts and glomerocrysts of sanidine(?) and quartz up to 7 mm. There are many euhedral and embayed quartz crystals. Groundmass is spherulitic to granophyric and composed of quartz and alkali feldspar with spherulites to 0.5 mm. Mafic minerals are weathered.
J-K, 14, north bank of Blue Creek Loc. 34 F. S. No. 394	Dike, 20 feet thick, exposed 1 mile	*Rhyolite porphyry*. Quartz and weathered feldspar phenocrysts up to 5 mm occur in dense dark gray nearly cryptocrystalline groundmass with abundant minute needles of weathered sodic amphibole(?).
J-K, 14–15, west and north flanks of Sierra Quemada Loc. 35 F. S. No. 930	Series of dikes, 0 to 50 feet thick	*Rhyolite porphyry*. Not studied in detail.
H, 14, west of Sierra Quemada Loc. 36 F. S. No. 802F	Dike, 30 feet thick, curved exposure 0.6 mile	*Porphyritic rhyolite*. Anhedral to subhedral embayed quartz up to 2 mm and weathered microperthite phenocrysts up to 3 mm occur in a dense xenomorphic-granular groundmass of quartz and alkali feldspar with grains and clots of weathered mafic minerals.
H-J, 14–16, Sierra Quemada, southern Chisos Mountains, south flank Loc. 37 F. S. No. 43BC	Laccolith mass, southern Chisos Mountains, about 3 miles in diameter	*Riebeckite-biotite microgranite porphyry*. Pinkish, mainly hypautomorphic-granular seriate rock 0.2 to 2 mm with some feldspar phenocrysts up to 4 mm. Feldspar is microperthitic; some has vermicular micrographic intergrowths along margins. Ferromagnesian minerals include orange-red biotite ($2V = 20° \pm$) and riebeckite poikilitic to quartz and feldspar. Zircon and fluorite are relatively abundant. Minute needles of tourmaline(?) occur in quartz. There is a trace of brown spinel(?). Quartz, 22%; perthite, 71%; riebeckite and biotite, 6%; fluorite, zircon, ore minerals, and spinel, 1%.
J, 15, Sierra Quemada, north flank Loc. 38 F. S. No. 135	Laccolithic mass, southern Chisos Mountains, about 3 miles in diameter	*Tourmaline microgranite porphyry*. Brownish-gray rock with microperthite and quartz phenocrysts up to 4×7 mm. The mass of the rock is a xenomorphic-granular aggregate of quartz and alkalic feldspar, average grain size 0.07 mm. Plumose blue tourmaline ($nE = 1.663$, $nO = 1.696$) replaces biotite, is poikilitic to quartz and feldspar, and also occurs as rare minute needles in quartz. Fluorite is relatively abundant. There is a trace of zircon.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
H-J, 14–15, Sierra Quemada, Picachio ridge Loc. 39 F. S. No. 136AB	Spinelike ridge cutting larger intrusion at Sierra Quemada	*Aegirine-augite granite porphyry.* Gray to brown rock with feldspar phenocrysts up to 10 mm; quartz is smaller; the groundmass is mainly micrographic. Feldspar phenocrysts are orthoclase, some with oligoclase cores and some microperthitic; aegirine-augite(?) is weathered. There is a trace of zircon, fluorite, and ore minerals. Another sample lacks plagioclase and has a fine granular groundmass without micrographic texture and with biotite and a trace of tourmaline.
H-J, 14–15, Sierra Quemada, west flank Loc. 40 F. S. No. 138	Outer rim of intrusion	*Augite microgranite porphyry.* Weathered light gray rock with microperthite and rare oligoclase phenocrysts up to 7 mm. Groundmass is a hypautomorphic-granular aggregate of alkali feldspar and quartz, average grain size 0.1 mm. Gray-green augite, some subhedral, is up to 0.8 mm. Quartz, 17%; feldspar, 69%; augite, 8%; ore grains, 6%; zircon and fluorite, tr.
H, 14, Sierra Quemada, marginal rock, west flank Loc. 41 F. S. No. 139	Outer rim of intrusion	*Granophyre.* Feldspar and quartz phenocrysts in an altered fine-grained, chocolate-colored, poorly granophyric groundmass. There is only a trace of mafic minerals.
H, 14, Sierra Quemada, west flank Loc. 42 F. S. No. 802A	Outer rim of intrusion	*Porphyritic rhyolite.* Abundant weathered microperthitic feldspar phenocrysts up to 7 mm, rare quartz grains up to 1.5 mm, and abundant feldspar spherulites to 0.4 mm occur in a dense quartzofeldspathic groundmass. Mafic minerals weathered to limonite and ore grains; there is a trace of zircon.
K-M, 15–17, Chisos Mountains pluton (see pp. 245–250) Loc. 43	Ward, Vernon Bailey, Pulliam Peaks, and minor masses	See pages 177–179.
M, 16, 0.5 mile north of Vernon Bailey Peak Loc. 44 F. S. Nos. 888, 759C	Dikelike, 10 to 50 feet thick, exposed 0.3 mile	*Porphyritic microgranite.* Rock is composed of a xenomorphic-granular seriate aggregate of microperthitic feldspar and quartz poikilitic to feldspar with average grain size of 0.1 mm along with sparse phenocrysts of sanidine ($2V = 20° \pm$) and embayed and corroded quartz about 1 mm. Spongy masses up to 1.3 mm of limonitic material probably were derived from original riebeckite.
N-O, 17, near road junction east of Government Spring laccolith Loc. 45 F. S. Nos. 370, 707	Dike, 2 to 5 feet thick, exposed with interruptions 0.5 mile	*Alkalic granophyre.* Abundant weathered alkali feldspar phenocrysts up to 4 mm, quartz, some euhedral, to 3 mm occur in a weathered hypautomorphic-granular to granophyric groundmass. Mafic minerals are completely altered.

M-N, 17, between Pulliam Bluff and Government Spring laccolith Loc. 46 F. S. Nos. 36, 472	Four dikes, 25 feet thick, subparallel, exposed 1.5 miles	*Alkalic microgranite porphyry*. Whitish to lavender porphyritic rock with quartz and feldspar phenocrysts up to 7 mm. Matrix is a dense hypautomorphic-granular to fine micrographic aggregate of quartz and alkali feldspar. Quartz phenocrysts are embayed; feldspar phenocrysts are orthoclase (nZ = 1.526) and perthite. There are discrete grains of weathered mafic minerals, probably riebeckite, and a trace of fluorite in vugs.
L, 17, west flank of Lost Mine Peak Loc. 47 F. S. No. 667E	Discordant, dikelike, 100 feet thick, exposed 0.4 mile	*Riebeckite rhyolite*. Greenish-gray rock with abundant altered riebeckite(?) prisms in clots and sponges in a dense feldspathic groundmass with rare microphenocrysts of sanidine-anorthoclase and quartz.
L, 16, Basin area, small peak at concessions area Loc. 48 F. S. No. 234	Plug, 0.1 mile in diameter	*Riebeckite microgranite porphyry*. Dove-gray groundmass with abundant white sanidine phenocrysts (2V = 20°±) up to 7 × 10 mm and quartz phenocrysts (some euhedral) up to 5 × 6 mm. Groundmass is a hypautomorphic-granular (limited micrographic areas) aggregate of alkali feldspar laths average 0.1 mm, quartz average 0.5 mm, and riebeckite poikilitic to quartz and feldspar up to 0.4 mm in bands. Fluorite and ore grains occur in traces.
L, 16, Basin area, immediately southeast of small peak at concessions area Loc. 49 F. S. No. 238	Sill, 45 feet thick, exposed 0.2 mile	*Riebeckite microgranite porphyry*. Light gray rock with white sanidine (2V = 20°±, extinction 13° on 010) and greasy quartz phenocrysts up to 3 × 6 mm. Groundmass is a hypautomorphic-granular, partly micrographic, aggregate of grains of quartz, laths of alkali feldspar, and irregular grains of riebeckite poikilitic to feldspar with grain size 0.2 to 0.4 mm. Opaque grains and fluorite occur in traces.
L, 16, Basin area, 0.3 mile west of Lone Peak Loc. 50 F. S. No. 947	Dikelike, 300 × 50 feet	*Riebeckite microgranite porphyry*. Weathered; not sampled.
L, 16, 1 mile north of Emory Peak Loc. 51 F. S. No. 911A	Tabular, sill-like, 30 feet thick, exposed 0.3 mile	*Rhyolite porphyry*. Anhedral to subhedral phenocrysts of sanidine (2V = 30°±), some with Carlsbad twins up to 8 × 10 mm, and subhedral to euhedral quartz up to 2 × 2 mm occur in a weathered buff-colored groundmass of quartz, alkali feldspar, and mafic minerals with average grain size of 0.1 mm. Micropegmatite is rare.
L, 16, east flank of Ward Mountain Loc. 52 F. S. No. 735	Dike(?) poorly exposed	*Rhyolite*(?). Rock weathered cryptocrystalline with a few altered feldspar phenocrysts and rare quartz grains.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
L, 16, on Toll Mountain Loc. 53 F. S. Nos. 454, 729	Dike, 30 to 50 feet thick, cutting lava	*Rhyolite porphyry.* Light pinkish-gray rock with abundant phenocrysts and glomerocrysts up to 5 × 5 mm. Groundmass, average grain size 0.05 mm, is composed of laths of alkali feldspar, grains of quartz, and minute dark grains and needles, probably a pyroxene or amphibole, along with a trace of micropegmatite and zircon. Phenocrysts are euhedral to anhedral sanidine (2V = 25° ±) with Carlsbad twins and euhedral to anhedral quartz with numerous liquid and gas inclusions. There is a trace of micropegmatite in phenocrysts.
K, 16–19, east side Chisos Mountains Loc. 54 F. S. Nos. 662ABC, 336D, 689F, C28	Dikelike, 60 feet to 0.25 mile wide, exposed 5.5 miles	*Riebeckite granophyre.* Reddish chocolate-brown porphyritic rock with quartz and sanidine (2V = 25° ±, Carlsbad twins) phenocrysts and glomerocrysts up to 8 × 10 mm in a granophyric groundmass. Mafic minerals are absent or dustlike in some samples but include riebeckite grains and plates to 0.3 mm in others. Zircon occurs as a trace.
K, 17, west side of Juniper Canyon Loc. 55 F. S. No. 156	Tabular, generally concordant, 50 feet thick, exposed 1 mile	*Alkalic microgranite porphyry.* Brownish-gray rock with abundant weathered microperthite and quartz phenocrysts and glomerocrysts to 3 × 4 mm in a xenomorphic-granular to granophyric groundmass. Weathered mafic minerals are probably riebeckite; zircon and fluorite occur as traces.
K, 17, west side of Juniper Canyon immediately south of F. S. 156 Loc. 56 F. S. No. 157	Tabular mass generally concordant, exposed ¾ square mile	*Alkalic microgranite porphyry.* Similar to Loc. 50.
J-K, 17–19, west side of Juniper Canyon drainage Loc. 57 F. S. Nos. 154–166, 167, 169, 355, 155, 738, 348AB, 352AB, 160, 168; 155 is plug	Group of dikes and sills, 10 to 40 feet thick, some exposed for 1.5 miles and one small pluglike mass	*Riebeckite granophyre.* Generally gray to brown rock with microperthite and quartz phenocrysts to 7 mm and granophyric to spherulitic groundmass. Some samples show a hypautomorphic-granular groundmass. Riebeckite occurs in most samples, with traces of fluorite and zircon. One sill is quartz-augite microgranite more coarse grained than Loc. 53. Aegirine is present in some samples.
J, 17, 1.5 miles north of Tortuga Mountain Loc. 58 F. S. No. 161	Sill-like, irregular, 1.5 × 0.8 miles, with bedded aspect due to jointing	*Microgranite.* Light gray xenomorphic-granular aggregate of feldspar 83%, quartz 8%, pyroxene 5%, ores 4%, analcime trace, apatite trace. Feldspar is composed mainly of grains and subhedral crystals of perthite, minute to 0.9 mm. Weathered and rare glomerocrysts of oligoclase (4 × 4 mm) are partly replaced by analcime. Clinopyroxene has ZAc = 34°. Quartz is interstitial and poikilitic to feldspar to 0.9 mm.

J, 17, 1.5 miles north of Tortuga Mountain Loc. 59 F. S. No. 153	Three dikes, 5 to 10 feet thick, exposed 0.2 mile	*Rhyolite.* White to gray weathered rock with a granophyric(?) groundmass.
J, 17, pass north of Tortuga Mountain Loc. 60 F. S. No. 353	Sill, 15 feet thick, exposed 0.25 mile	*Alkalic granophyre.* Gray rock with weathered feldspar phenocrysts up to 1 mm, quartz 0.4 mm, and completely weathered mafic minerals in a granophyric groundmass up to 0.3 mm.
J, 16, 1 mile northwest of Tortuga Mountain Loc. 61 F. S. No. 936	Discordant, pluglike, 0.4 mile in diameter (photogeology)	*Microgranite.* Not studied in detail.
J, 16–17, southern Chisos Mountains Loc. 62 F. S. Nos. 152, 159, 938	Two dikes, 20 feet thick, one exposed 3.5 miles cuts Locs. 61 and 58; other exposed 1 mile cuts Loc. 58	*Riebeckite granophyre.* Flesh-colored weathered feldspar and greasy quartz phenocrysts to 4 × 7 mm, some euhedral, occur in a gray granophyre. Groundmass with grains and sponges of riebeckite and a trace of zircon and fluorite.
H-J, 17, Tortuga Mountain, southern Chisos Mountains Loc. 63 F. S. Nos. 162ABC	Discordant plug or stock doming surrounding rocks	*Riebeckite-biotite granite.* Gray, almost white, rock with prominent black grains essentially equigranular with range in grain size of 0.2 to 2 mm (from specimen to specimen) and sporadic phenocrysts 3 × 5 mm. Texture is hypautomorphic-granular with considerable micropegmatite in some specimens. Feldspar is microperthite. Riebeckite crystals and sponges are up to 4 mm, poikilitic to quartz and feldspar, and intergrown with biotite; opaque minerals are lacking, zircon is relatively abundant, and there is a trace of fluorite and brown isotropic minerals of high index. (1) Quartz, 33%; feldspar, 51%; riebeckite, 14%; biotite, 2%. (2) Quartz, 33%; feldspar, 61%; riebeckite and biotite, 6%.
J, 17, 1 mile northeast of Tortuga Mountain Loc. 64 F. S. No. 303	Dike, 30 feet thick, exposed 1.2 miles	*Spherulitic riebeckite granophyre.* Gray rock with rare quartz phenocrysts, some euhedral, up to 2 mm in a fine granophyric groundmass in which are black spherulites up to 4 mm. Slender prismatic to acicular riebeckite to 2 mm long, some intergrown with aegirine and some in spherulites occurs in the spherulitic structure.
H-J, 18, 2 miles east of Tortuga Mountain Loc. 65 F. S. No. 806	Discordant, dikelike, 0.8 mile × 150 feet	*Porphyritic riebeckite microgranite.* Anhedral to subhedral embayed quartz and weathered alkali feldspar phenocrysts to 4 mm, together with discrete grains and aggregates of riebeckite to 0.8 mm poikilitic to quartz and feldspar, occur in a groundmass of weathered laths of alkali feldspar and anhedral grains of quartz average 0.15 mm. There are traces of fluorite, zircon, and aegirine. Rare ore grains replace riebeckite.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
H, 18, 2 miles southeast of Tortuga Mountain Loc. 66 F. S. Nos. 164, 165, 300	Dike, 25 feet thick, dipping 45°, forms dip slope	*Porphyritic riebeckite microgranite.* Weathered microperthite(?) and quartz phenocrysts and glomerocrysts to 4 × 4 mm occur in a bluish-gray, xenomorphic-granular to partly granophyric groundmass. Feldspar and quartz in the groundmass average 0.1 mm. Riebeckite(?) is abundant, 18% average 0.15 mm, rarely 0.5 mm in discrete non-poikilitic grains. Aegirine(?), epidote(?), zircon, and fluorite occur as traces. A marginal sample has 26% riebeckite and a fine groundmass, average 0.05 mm.
H, 18, 2 miles southeast of Tortuga Mountain Loc. 67 F. S. No. 562	Two sills, about 20 feet thick, one capping hill	*Porphyritic riebeckite microgranite.* Similar to F. S. 300, Loc. 66.
M-N, 18, Panther laccolith Loc. 68 F. S. Nos. 53AB, 658, 691AB	Irregular laccolith, 1 × 2 miles	*Porphyritic sodic rhyolite.* Rock is a greenish-gray dense aggregate of alkali feldspar, green clinopyroxene (augite?), and about 10% quartz (average grain size about 0.06 mm) with phenocrysts and glomerocrysts of altered alkali feldspar to 5 mm, poikilitic to pyroxene and ore grains. Microphenocrysts of pyroxene are about 0.3 mm; biotite and riebeckite are locally intergrown. There is a trace of fayalitic olivine(?) in crystals largely altered to iron oxide and as inclusions in feldspar. There is a trace of apatite and zircon.
N, 19, 1 mile south slightly west of Park headquarters Loc. 69 F. S. No. 694	Plug, 0.3 mile in diameter	*Rhyolite.* Weathered dense felty aggregate of alkali feldspar with about 10% quartz and mafic minerals and sporadic feldspar phenocrysts.
N, 19, immediately east of Park headquarters Loc. 70 F. S. Nos. 31, 342, 409	Sill(?), 75 feet thick, faulted, roughly oval outcrop 0.7 mile with several isolated exposures	*Sodic granophyre.* Lavender-gray porphyritic rock with a dense matrix. Quartz and feldspar (orthoclase partly perthitic) and embayed quartz phenocrysts are up to 3 × 5 mm. Matrix is mainly micrographic up to 0.2 mm. Weathered sodic(?) ferromagnesian mineral and zircon occur as traces.
N, 21, 1¼ miles northwest of Estufa Canyon Loc. 71 F. S. No. 672A	Small dike	Not described; slide lost.

M, 18–19, northeast flank of George Wright Peak Loc. 72 F. S. No. 692A	Dike, 40 feet thick, exposed 0.9 mile	*Rhyolite.* Gray, dense, felty aggregate of alkali feldspar, about 10% quartz and mafic minerals. Originally contained sporadic feldspar phenocrysts.
M, 19, Pummel Peak, 2.5 miles southwest of Park headquarters Loc. 73 F. S. Nos. 26A, 683D	Pluglike intrusive mass 0.2 mile in diameter forming spine	*Sodic rhyolite porphyry.* Greenish-gray porphyritic rock with weathered orthoclase(?) phenocrysts to 3 × 4 mm and microphenocrysts of riebeckite and aegirine-augite to 0.6 mm. Dense groundmass is composed of alkali feldspar, quartz, and mafic minerals.
M, 19, 1 mile north of Pummel Peak Loc. 74 F. S. No. 693	Irregular dike, 20 feet thick	*Rhyolite.* Weathered dense felty aggregate of alkali feldspar, about 10% quartz and mafic minerals. Originally contained feldspar phenocrysts.
M, 19, 1 mile northeast of Pummel Peak Loc. 75 F. S. No. 934	Sill remnant(?), 0.1 mile in diameter	*Rhyolite.* Not studied in detail.
M-N, 19, 1.5 miles southeast of Park headquarters Loc. 76 F. S. No. 32	Tabular, dipping, about 50 feet thick, slightly discordant	*Riebeckite granophyre.* Lavender-gray porphyritic rock with feldspar phenocrysts up to 7 mm, quartz up to 3 mm, and riebeckite up to 1 mm. Matrix is hypautomorphic-granular to micrographic 0.02 to 0.2 mm. Feldspar phenocrysts are weathered orthoclase(?), some perthitic; riebeckite occurs in irregular grains and prisms; there is a trace of zircon and fluorite. Quartz contains abundant liquid inclusions.
M, 20, 2.5 miles southeast of Park headquarters Loc. 77 F. S. No. 33	Discordant, dikelike, 50 feet thick, exposed 1.3 miles	*Riebeckite granophyre.*
M, 19, 1.5 miles northeast of Pummel Peak Loc. 78 F. S. No. 509G	Dike, 40 feet thick, exposed 0.5 mile	*Rhyolite.* Weathered cream-colored dense xenomorphic-granular aggregate of quartz, alkali feldspar, and limited sodic(?) ferromagnesian mineral.
M, 19, west flank of Loc. 75 Loc. 79 F. S. No. 473A, 790	Discordant lens, 40 × 500 feet, dipping 75°	*Granophyre.* Weathered light gray rock with embayed subhedral equant quartz phenocrysts to 5 mm and equant microperthitic phenocrysts to 8 mm in a granophyric groundmass. There is a trace of zircon. Mafic minerals are limited to fine opaque dust.
M, 19, 2 miles southeast of Park headquarters Loc. 80 F. S. No. 473B	Tabular, dipping, about 50 feet thick, slightly discordant	*Granophyre.* Similar to Loc. 44 except that the rock is weathered and lacks riebeckite crystals.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
M, 19, at south flank of mass 75 Loc. 81 F. S. No. 474BC	Two sills, 10 to 30 feet thick, exposed sporadically 0.5 mile	*Rhyolite.* Dense xenomorphic-granular aggregate of ragged laths of alkali feldspar, quartz grains, and completely altered minute grains of mafic minerals with rare glomerocrysts and altered alkali feldspar to 5 mm.
M, 20, crossed by highway Loc. 82 F. S. No. 474A	Discordant, dikelike, irregular, 100 feet × 0.2 mile	*Alkalic granophyre.* Weathered rock composed of embayed subhedral quartz phenocrysts in light gray granophyric groundmass. Mafic minerals are completely weathered. There is a trace of zircon.
M, 19, 1.5 miles east of Pummel Peak Loc. 83 F. S. Nos. 509JK, 535, 535A	Dike, 10 to 30 feet thick, irregular, branching in places, exposed 1 mile	*Porphyritic rhyolite.* Brownish-gray xenomorphic-granular aggregate of alkali feldspar and quartz, average grain size 0.1 mm, with phenocrysts of anorthoclase(?) up to 3 × 2 mm. Quartz comprises about 10%.
M, 19, 1.5 miles northwest of Nugent Mountain Loc. 84 F. S. No. 29AB	Discordant, tabular, dipping, 200 feet thick, related to F. S. 543 (Loc. 91)	*Riebeckite rhyolite.* Gray slightly porphyritic rock with weathered alkali feldspar phenocrysts to 2 × 3 mm. Groundmass is subtrachytic aphanitic to fine grained with laths of alkali feldspar, ragged prisms and sponges of riebeckite, interstitial quartz, and micropegmatite. There is a trace of fluorite in veinlets.
M, 20, 2 miles north of Nugent Mountain Loc. 85 F. S. No. 544	Dike, 25 feet thick, exposed 0.1 mile	*Rhyolite porphyry.* Similar to Loc. 79; not studied in detail.
M, 20, 1.5 miles north of Nugent Mountain Loc. 86 F. S. No. 940	Sill-like, 25 feet thick, exposed 0.3 mile	*Rhyolite.* Similar to Loc. 79; not studied in detail.
M, 20, 4 miles southeast of Park headquarters Loc. 87 F. S. No. 8	Sill, 75 feet thick	*Porphyritic microgranite.* Grayish-green weathered, porphyritic rock with a hypidiomorphic-granular groundmass 0.1 to 0.2 mm. Phenocrysts are perthite 2 to 3 mm; mafic minerals are weathered sodic pyroxene(?); quartz is interstitial.
L, 19, 1.5 miles north of Hayes Ridge Loc. 88 F. S. No. 540	Pluglike, 100 feet thick, exposed 0.3 mile	*Rhyolite.* Chocolate-colored dense xenomorphic-granular partly spherulitic aggregate of alkali feldspar, quartz, and weathered mafic minerals with rare weathered alkali feldspar phenocrysts to 3 × 2 mm.

L-M, 19, 1 mile southeast of Pummel Peak Loc. 89 F. S. Nos. 536, 537	Two sills, 10 and 40 feet thick, exposed 1 mile	Upper sill, *rhyolite*, brown weathered aggregate of alkali feldspar laths average length 0.4 mm, about 10% interstitial quartz and abundant weathered ferromagnesian mineral; lower sill, *rhyolite*, is a felty aggregate of minute laths of weathered alkali feldspar, discrete quartz grains, and weathered ferromagnesian mineral.
L, 19–20, northwest of Nugent Mountain and north of Hayes Ridge Loc. 90 F. S. Nos. 477, 478, 542, 791ABCDE	Group of 7 dikes, 8 to 50 feet thick, exposed 0.2 to 1.3 miles; one oval in plan 50 × 100 feet	*Alkalic granophyre.* Reddish weathered rock with prominent doubly terminated quartz and weathered alkali feldspar phenocrysts to 5 mm. Groundmass is granophyric to spherulitic. Sodic(?) mafic minerals are weathered; there is a trace of fluorite. Ore grains are abundant in one section.
L-M, 20, 0.5 mile north of Nugent Mountain Loc. 91 F. S. No. 543	Discordant, roughly tabular, dipping, 150 feet thick, exposed 1 mile, exposure interrupted by alluvium	*Porphyritic alkalic rhyolite.* Dense aggregate of laths of alkali feldspar average 0.2 mm long with subtrachytic texture, with phenocrysts and glomerocrysts of weathered alkali feldspar to 3 × 5 mm; rock is about 10% interstitial quartz and about 15% weathered mafic minerals.
L, 20, northeast flank of Nugent Mountain Loc. 92 F. S. Nos. 471, 559, 560, 561	Four dikes, 5 to 10 feet thick, exposed irregularly on flank of mountain and in drainage	*Rhyolite.* Gray to brown weathered aggregates of alkali feldspar quartz and sodic(?) mafic minerals. Sporadic alkalic feldspar phenocrysts are up to 2 mm. One dike has quartz phenocrysts.
L, 21, 1 mile east of Nugent Mountain Loc. 93 F. S. Nos. 202, 202NS	Sill, 40 feet thick	*Porphyritic alkalic microgranite.* Sanidine-anorthoclase with prominent Carlsbad twins to 5 × 9 mm and aegirine-augite ($X_{\Lambda}c = 37°$) to 0.2 × 0.99 mm as phenocrysts in a green groundmass of laths and alkali feldspar about 0.1 mm, riebeckite and aegirine-augite to 0.3 mm poikilitic to quartz and feldspar, ore grains, and quartz. Groundmass in some specimens is granophyric. Mafic minerals comprise 10% of the rock; there is a trace of fluorite.
L, 20, 0.4 mile southeast of Nugent Mountain Loc. 94 F. S. No. 534	Dike, 7 feet thick, exposed in 300 feet in arroyo	*Granophyre.* Brownish rock with weathered flesh-colored microperthite(?) phenocrysts to 10 mm and quartz phenocrysts to 4 mm in an obscure granophyric groundmass; granophyric grains average 0.1 mm are separated by films of turbid secondary material originally mafic(?).
L, 20, Nugent Mountain Loc. 95 F. S. Nos. 201, 218, C25, 792	Plug, 0.6 mile in diameter	*Alkalic microgranite.* Margin of mass is trachytic with turbid feldspar laths, rare orthoclase(?) phenocrysts ($2V = 60° \pm$), abundant arfvedsonite(?), rare aegiritic pyroxene, and about 10% quartz. Samples from center are weathered xenomorphic-granular seriate rock with mafic minerals completely altered.
L, 19–20, 1 mile southwest of Nugent Mountain Loc. 96 F. S. Nos. 286, 736	Dike, 25 feet thick, exposed 0.3 mile; two small additional exposures to east	*Rhyolite porphyry.* Dark green porphyritic rock; quartz and weathered perthitic feldspar phenocrysts are up to 5 mm. Matrix is dense xenomorphic-granular with abundant minute grains of aegirine-augite(?).

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
K-L, 19, 1.5 miles southwest of Nugent Mountain Loc. 97 F. S. No. 28	Discordant, tabular mass, exposed in area 1 × 0.5 mile, 60 feet thick	*Riebeckite granophyre.* Light gray porphyritic rock with quartz and feldspar (mainly orthoclase, rarely orthoclase-albite perthite) phenocrysts up to 3 × 5 mm. Groundmass is micrographic to hypautomorphic-granular. Micrographic intergrowths average 0.2 mm. Quartz is embayed; anhedral riebeckite is up to 0.4 mm.
K, 19–20, southeast flank Hayes Ridge Loc. 98 F. S. No. 580BCEF	Four dikes, 10 to 40 feet thick	*Sodic granophyre.* Light gray rock with chalky microperthite and greasy quartz phenocrysts to 8 mm and granophyric to hypautomorphic-granular groundmass. Mafic minerals are weathered. Some specimens contain sodic amphiboles and anomalous aegirine-augite(?) and aegirine. Fluorite grains are prominent in some specimens.
K, 20, 1.5 miles south of Nugent Mountain Loc. 99 F. S. No. 364	Dike, 5 feet thick, exposed 0.1 mile	*Alkalic granophyre.* Weathered with abundant secondary minerals.
H, 20, 1 mile west of Glenn Springs Loc. 100 F. S. No. 11, 11A	Laccolith, outcrop irregularly oval 1 mile square	*Porphyritic microgranite.* Lavender-gray weathered, porphyritic rock with phenocrysts and glomerocrysts to 5 mm. Groundmass is trachytic with laths 0.1 to 0.5 mm. Estimated mode: orthoclase laths, 71%; quartz poikilitic to orthoclase, 17%; weathered mafic minerals, 12%.
H, 20, 0.5 mile northwest of Glenn Springs Loc. 101 F. S. No. 356	Sill, 50 feet thick, probably related to Loc. 100	Similar to Loc. 100.
J, 22, 2.5 miles east of Chilicotal Mountain Loc. 102 F. S. No. 714	Discordant, vertical mass, 500 feet thick, elongate thinning to dike proportions, 0.7 mile long	*Microgranite.* Gray hypautomorphic-granular seriate rock with grain size from 0.1 to 3 mm; euhedral constituents are minor. Anhedral to euhedral anorthoclase ($2V = 55° \pm$) occurs as larger grains with oligoclase cores; some show Carlsbad twins, gridiron twins are rare. Completely altered pyroxene(?) constitutes approximately 15%, interstitial quartz and micropegmatite about 10%, apatite, tr.

G, 10, 0.5 mile northwest of Cerro Castellan Loc. 103 F. S. Nos. 669AB, 564	Five vertical cylindrical pipes 8 to 15 feet in diameter, largest 20 feet high emplaced in volcanic ash, and two dikes 30 feet thick, exposed 1 mile	*Pumiceous rhyolite.* White to gray pumiceous rock with rare euhedral feldspar (anorthoclase?) phenocrysts in a glassy to spherulitic matrix. Phenocrysts are up to 1 mm; spherulites are up to 0.1 mm, rare prisms and needles of riebeckite and aegirine-augite are up to 0.05 mm. Some specimens are mainly perlitic glass ($n = 1.50$); some are devitrified or crystallized to a dense feldspathic aggregate.
G, 10, east flank of Cerro Castellan Loc. 104 F. S. Nos. 771, 773	Plug, 0.1 mile in diameter, forming part of peak	*Porphyritic riebeckite-aegirine rhyolite.* Even gray to gray and black rock with euhedral sanidine-anorthoclase phenocrysts to 1.5 mm; riebeckite and aegirine occur in sponges and discrete grains to 0.8 mm and are poikilitic to quartz, grains average 0.1 mm and alkali feldspar laths to 0.05 mm; there is abundant interstitial microcrystalline material. Areas of chalcedony and ore grains formed from alteration of mafic minerals. Riebeckite and aegirine are not uniform in distribution.
F, 11, 3.5 miles southeast of Cerro Castellan Loc. 105 F. S. Nos. 747B, 801D	Irregular, dikelike, generally discordant, 30 to 50 feet thick, exposed 0.5 mile	*Riebeckite rhyolite.* Green fine to aphanitic rock with no visible quartz; rare sanidine microphenocrysts are up to 0.4 mm. Groundmass of quartz grains is mainly poikilitic to minute laths of feldspar. Riebeckite to 0.3 mm is abundant; some is intergrown with aegirine; some is in poikilitic sponges.
G, 12, 1 mile northwest of Round Mountain Loc. 106 F. S. Nos. 279, 650	Tabular to irregular, discordant, 100 feet thick, exposed 0.5 mile	*Riebeckite rhyolite.* Greenish gray with imperfectly granophyric groundmass in which grains of quartz to 0.1 mm are intergrown with minute laths of alkali feldspar. Minute needles, prismatic grains, and skeletal crystals of riebeckite (the latter, up to 0.2 mm) are abundant. Aegirine occurs as traces, some is intergrown with riebeckite. Phenocrysts and microphenocrysts of sanidine to 2 mm are rare.
G, 12, 1 mile northwest of Mule Ear Peak Loc. 107 F. S. No. 566A	Dike, 10 feet thick, exposed 0.6 mile	*Sodic rhyolite.* Greenish-gray rock with phenocrysts of sanidine-anorthoclase up to 0.4 mm in a dense groundmass with abundant needles of aegirine(?) up to 0.05 mm.
G, 13, Mule Ear Peak Loc. 108 F. S. Nos. 280, 643E	Four dikes, 20 to 40 feet thick, exposed 0.4 mile; one becomes a tabular mass toward southwest	*Riebeckite rhyolite.* Rare sanidine-anorthoclase phenocrysts to 0.5 mm occur in a dense partly granophyric groundmass with tufts and grains of riebeckite. Some specimens contain aegirine.
G, 13, 0.9 mile northeast of Mule Ear Peak Loc. 109 F. S. No. 898	Pluglike, 50 × 300 feet	*Rhyolite.* Rock is a dense aggregate of alkali feldspar microlites average 0.05 mm, quartz grains up to 0.15 mm and needles of green sodic ferromagnesian mineral(?) to 0.15 mm, along with rare euhedral to subhedral phenocrysts of alkali feldspar up to 1.1 × 0.8 mm almost completely replaced by calcite.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
G, 13, 1 mile northeast of Mule Ear Peak Loc. 110 F. S. No. 899	Plug, 40 × 60 feet; dike, same rock 10 feet thick, exposed 100 feet, 100 yards southeast	*Rhyolite.* Light gray, dense, obscurely granophyric rock with rare weathered euhedral to subhedral phenocrysts of potassium feldspar and oligoclase(?) up to 0.4 × 0.7 mm; minute prisms and grains of weathered sodic ferromagnesian mineral(?) are abundant.
F-G, 16, Dominguez Mountain and dike swarm extending southwest into D, 12 (see pp. 257–265; 269–270) Loc. 111	Dominguez Mountain—a composite intrusion with dike swarm	See pages 180–186.
G, 17, Backbone Ridge immediately due east of Dominguez Mountain Loc. 112 F. S. Nos. 45, 720	Discordant, pluglike, 0.4 × 0.8 mile	*Porphyritic leucorhyolite.* Some samples are quartz trachyte without micrographic texture.
E, 19, north end of Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 113 F. S. No. 832	Irregular mass capping hill	*Rhyolite.* Weathered gray dense aggregate of alkali feldspar and quartz with imperfect or rudimentary granophyric texture, minute limonitic grains from alteration of mafic minerals, microphenocrysts of quartz and weathered alkali feldspar.
E, 19, north end of Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 114 F. S. Nos. 18A, 428	Sill, 10 feet thick	*Rhyolite.* White rock with rare phenocrysts of alkali feldspar to 4 mm. Groundmass is granophyric with rare spherulites 0.02 mm.
E, 19, north end of Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 115 F. S. Nos. 18B, 427	Sill, 4 feet thick, exposed 0.2 mile	*Spherulitic vitrophyre.* Rudimentary spherulites to 0.3 mm and phenocrysts of anorthoclase, aegirine-augite, and olivine occur in a dark glass matrix (n = 1.49). Glass is partly devitrified in bands; some trichites. Zircon occurs as a trace.

E, 19, west flank Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 116 F. S. Nos. 426, 329, 427, 428, 507AB, 508A	Disconnected sill and discordant masses, 2 to 15 feet thick, exposed 100 feet to 0.5 mile with brown weathered outcrop	*Rhyolite* to *quartz trachyte.* Brownish-gray to brown, dense to very fine-grained, weathered rock, some with weathered feldspar phenocrysts, some granophyric or spherulitic; mafic minerals in grains and needles are completely altered to iron oxide.
D-E, 20–21, east flank Mariscal Mountain Loc. 117 F. S. Nos. 22AB, 418, 523	Sill, 60 feet thick, divided by sedimentary band	*Alkalic microgranite* (lower part). Light gray, dense, felty rock, grain size 0.2 mm, with rare phenocrysts 2 mm. Amygdules with chalcedony are rare; quartz is interstitial and poikilitic to feldspar. Mafic minerals are weathered. *Porphyritic microgranite* (upper part). Porphyritic rock with feldspar phenocrysts to 1 cm in a felty to micrographic groundmass. Sodic pyroxene(?) is weathered; chalcedony and calcite are present.
D-E, 22–23, east of Mariscal Mountain near Rio Grande Loc. 118 F. S. Nos. 858, 305, 524	Sills varying from 10 to 50 feet in thickness, multiple in places; small dike offshoots	*Spherulitic microgranite.* Light gray to pink weathered xenomorphic-granular aggregate of alkali feldspar laths in spherulitic groups average size 0.8 mm, weathered mafic minerals and interstitial quartz (10%±). There are rare phenocrysts of perthite to 2.0 mm and mafic minerals, partly in needles, in the spherulitic aggregates.
F-G, 19–20, southwest flank of Talley Mountain Loc. 119 F. S. No. 530	Sheetlike, 200 feet thick, exposed irregularly over area of 2 square miles	Similar to main rock, Talley Mountain, Loc. 115.
F-G, 20–21, Talley Mountain, 2.5 miles southwest of Glenn Springs Loc. 120 F. S. Nos. 13AB, 217, 704AB	Tabular, probably concordant, maximum thickness about 400 feet. Possibly related to Chilicotal Mountain	*Porphyritic microgranite.* Light gray rock with dark specks, porphyritic; perthitic phenocrysts are up to 3 mm. Groundmass is hypautomorphic-granular 0.1 to 0.5 mm. Groundmass feldspar is sodic orthoclase, some with albite cores; quartz is interstitial; mafic minerals are completely altered.

ANALCITE ROCKS (Locs. 121–175)

Q, 1, Bone Spring mass (see "analcite suite," pp. 263–265) Loc. 121	Sill-like, up to 100 feet thick in Aguja Formation	See page 177.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
M-P, 3–5, and Q-T, 23–25, along west flank of Sierra del Carmen Loc. 122 F. S. Nos. 65, 124, 125A, 127, 128, 129, 130A, 131, 325A, 378	Sills, 10 to 40 feet thick, in two or more horizons in Boquillas Formation exposed sporadically through a distance of 18 miles; in many places with bands and stringers up to 2 feet of analcite syenite	*Diabasic analcite gabbro.* Ranges texturally to porphyritic and mineralogically to syenogabbro. Mainly dark gray, medium-grained aggregates of plagioclase (An_{60}–An_{74}), purple to grayish-purple augite, with some aegiritic rims, ophitic or subophitic to plagioclase, prominent ore grains with biotite, interstitial and ocellar analcite, apatite, and secondary material possibly from olivine. Average mode: feldspar and alteration products, 38%; analcite, 12%; mafic alteration products, 23%; augite, 15%; ore grains, 9%; hornblende, biotite, apatite, 3%.
F. S. 125B, 130B, 306AB		*Analcite syenite* bands a few inches to 2 feet thick. Weathered light gray, medium-grained aggregates of alkali feldspar (orthoclase?), purple augite with vivid green aegiritic rims, discrete grains of green aegiritic pyroxene, biotite, hornblende and apatite with abundant ocellar and interstitial analcite. Band in sill at Q, 24—feldspar, 69%; analcite, 24%; pyroxene, 7%; biotite, 1%; ores, 1%; hornblende, apatite, tr.
P, 12, west flank of Christmas Mountains (see N-O, 7, on inset map) Loc. 123 F. S. No. 405D	Dike, 20 feet thick, exposed 0.4 mile	*Analcite basalt.* Weathered relicts of plagioclase and clinopyroxene along with fresh ore grains, interstitial analcite, traces of minute green pyroxene or amphibole, biotite, and apatite needles.
P, 12, west flank of Christmas Mountains (see O, 7, on inset map) Loc. 124 F. S. Nos. 340C, 100A	Dike, 10 to 15 feet thick, exposed 0.6 mile	*Analcite basalt.* Dense felty aggregate of labradorite (An_{56}) laths, stubby prisms of purple augite, plates and shreds of biotite, ore grains, apatite prisms and needles, and ocellar and interstitial analcite. In places porphyritic with plagioclase glomerocrysts to 10 mm. Some interstitial alkali feldspar.
Q, 12, Christmas Mountains (see P, 7, on inset map) Loc. 125 F. S. No. 839	Dike, 4 feet thick, cutting large syenite sill	*Analcite basalt.* Dark gray to black with glomerocrysts of labradorite (An_{60}) up to 3×5 mm and microphenocrysts of serpentine after olivine and ilmenite altered to leucoxene in a groundmass of plagioclase laths, slender purple augite crystals, altered olivine, ore grains, apatite, and traces of biotite with abundant analcite in vesicles, veins, and interstices.

Q, 12, east flank of Christmas Mountains (see O, 9, on inset map) Loc. 126 F. S. No. 92B	Dike, 4 feet thick, exposed 0.1 mile	*Analcite basalt.* Weathered; originally an aggregate of plagioclase, purple augite, and ore grains with abundant interstitial analcite.
Q, 13, east flank of Christmas Mountains (see Q, 9, on inset map) Loc. 127 F. S. No. 76	Dike, 8 feet thick, exposed 0.3 mile	*Analcite basalt porphyry.* Dark gray with phenocrysts of labradorite (An_{58}) up to 2×5 mm and augite to 1×2 mm in subtrachytic groundmass of plagioclase laths up to 0.5×0.5 mm, grains of purple augite, ore grains, serpentine after olivine(?) and abundant interstitial analcite. Some ore grains altered to leucoxene; trace of biotite and apatite.
Q, 13, east flank of Christmas Mountains (see Q-R, 10, on inset map) Loc. 128 F. S. No. 78	Sill, 20 feet thick, exposed 1 mile	*Analcite andesine syenite.* Dark gray hypautomorphic-granular seriate aggregate with marked intersertal texture in which analcite fills interstices. Rare corroded phenocrysts of andesine (An_{40}) up to 2 mm; feldspar mainly sanidine-anorthoclase laths 0.3 to 0.6 mm, some with andesine cores. Rare euhedral purple augite phenocrysts to 2 mm; pyroxene mainly subhedral, smaller purple prismatic augite crystals, many zoned to emerald green aegiritic pyroxene. Ore grains in clots with brown secondary mineral, possibly originally olivine. Biotite and rare brown hornblende in minute grains and crystals. Apatite needles abundant. Analcite about 20% of rock, both clear and turbid replaces feldspar, is interstitial and ocellar enclosing and surrounding pyroxene, biotite, apatite, and feldspar.
Q, 13, east flank of Christmas Mountains (see R, 10, on inset map) Loc. 129 F. S. No. 926B	Mass, 12 feet in diameter (too small to map)	*Porphyritic analcite trachybasalt.* Dark gray to black with partly weathered hypautomorphic-granular groundmass seriate to 0.3 mm composed of laths and anhedral grains of alkali and plagioclase feldspar, anhedral to euhedral deep purple augite, analcite, ore grains, and apatite needles. Analcite about 10% is interstitial ocellar and in miarolitic cavities. Phenocrysts are labradorite (An_{64}) to 3×6 mm. Brown secondary minerals in clots to 2 mm possibly after olivine.
Q-R, 13, east of Christmas Mountains (see R, 11–12, on inset map) Loc. 130 F. S. Nos. 710AE, 914FGH	Tabular, discordant, 50 feet thick, exposed irregularly in area of 1 square mile	*Analcite syenogabbro.* Fine- to medium-grained hypautomorphic-granular aggregate of weathered plagioclase and alkali feldspar, fresh subhedral to euhedral purple augite, ore grains, olivine pseudomorphs, biotite, apatite, and interstitial analcite. Percentage of augite and biotite varies considerably.
P, 12, 0.5 mile east of Little Christmas Mountain (see N, 8, on inset map) Loc. 131 F. S. Nos. 406AB	Lens-shaped, partly discordant 0.2×0.3 mile	*Analcite syenogabbro.* Hypautomorphic-granular rock seriate up to 4 mm with average about 1.5 mm composed of subparallel laths of labradorite (An_{58}) armored with anorthoclase ($2V = 45° \pm$), grayish-purple augite ($nY = 1.685 \pm$), some subhedral, mainly in clots with ore grains, serpentinized olivine, and rare biotite. Analcite is interstitial and replaces labradorite. Contact specimens show little analcite and less alkali feldspar.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
P, 12, 1 mile east of Little Christmas Mountain Loc. 132 F. S. Nos. 95, 719	Sill, 12 feet thick, exposed 0.2 mile	*Analcite basalt porphyry.* Abundant phenocrysts and glomerocrysts of labradorite (An_{56}) up to 10 × 10 mm in sparse groundmass of anhedral to euhedral purple augite locally with green sodic rims, plagioclase laths, altered alkali feldspar, ore grains, apatite, and analcite. Analcite replaces plagioclase and is prominent in ocelli associated with biotite, minute sodic pyroxene, and apatite needles.
O, 12–13, north end of Chisos Pen Anticline Loc. 133 F. S. Nos. 70, 307, 853, 886	Sill, 25 to 30 feet thick, irregular, slightly discordant in places, curved outcrop 2.5 miles in north end of anticlinal structure	*Analcite microdiorite.* Gray, fine grained, with andesine (An_{45}) laths 0.2 to 0.5 mm rimmed with alkali feldspar slightly ophitic to augite, lavender subhedral to anhedral augite average about 0.3 mm, clots of biotite, ore grains, and green serpentine(?) about 0.3 mm, needles of apatite, grains of hornblende and interstitial and ocellar analcite. Rare phenocrysts of andesine are as large as 4 mm; clots of ore grains, biotite, and serpentine(?) appear to have formed from alteration of hornblende. Mode: alkali feldspar, 4%; andesine, 48%; augite, 11%; biotite, 11%; serpentine, 10%; analcite, 9%; ore grains, 7%; hornblende and apatite, tr. *Analcite hornblende porphyry.* Bands 3 to 6 feet thick and pockets in *analcite microdiorite* contain giant prismatic phenocrysts of brown hornblende (nX = 1.689; nY = 1.712; ZΛc = 23°; 2V large) up to 8 cm in length. All hornblende crystals are bordered by reaction rims of ore grains, serpentine(?), and biotite similar to clots in normal rock. The porphyritic rock appears to have more alkali feldspar and analcite than the normal type.
P, 13, north flank of Slickrock Mountain Loc. 134 F. S. No. 860A	Tabular, poorly exposed 0.3 × 0.3 mile; contains band of syenite to 8 inches thick	*Analcite andesine syenite.* Fine to medium grained with about 40% irregular to lath-shaped turbid anorthoclase (2V = 45° ±) crystals and 20% weathered andesine (An_{38}) laths. Mafic minerals include purple augite (ZΛc = 45°) with green aegiritic rims, minute grains and prisms of bright green aegirine-augite (ZΛc = 65°), irregular grains and rods of opaque minerals, and a trace of biotite and brown amphibole. Apatite needles are prominent. Analcite (5%) is interstitial and contains inclusions of apatite and aegirine-augite. Abundant brown secondary material in clots with opaque grains may be after olivine.
P, 13, 1 mile north of Slickrock Mountain Loc. 135 F. S. No. 274A	Sill-like, 50 to 75 feet thick, dipping steeply, exposed on crescent 0.5 mile wide and 1.75 miles long; surface is spectacular black slope visible for many miles	*Analcite syenogabbro* (analyzed sample). Dark gray, fine-grained, seriate rock containing pale violet-gray augite 0.2 to 2 mm ophitic to labradorite (An_{54}) laths 0.6 to 0.3 mm, maximum 1.4 mm; labradorite is commonly armored with sanidine-anorthoclase. Discrete grains of sanidine-anorthoclase are rare. Slightly serpentinized olivine occurs in rounded grains up to 0.5 × 0.6 mm in clusters with magnetite and biotite; some of latter form coronas. Apatite is in prismatic grains and needles to 0.6 mm. Analcite is interstitial. Mode: alkali feldspar, 16%; plagioclase, 49%; augite, 12%; olivine, 9%; ore grains, 6%; biotite, 4%; analcite, 3%; apatite, 1%.

R, 14, 2 miles northeast of Christmas Mountains Loc. 136 F. S. Nos. 72, 244	Laccolith, 125 feet thick, truncated edge exposed 0.7 mile intermittently in gullies and arroyos, margins chilled fine, interior fine to coarse with light syenitic bands to 6 inches thick	*Analcite melasyenite.* Group name for principal varieties of rocks in this mass, most of which contain minor analcite and abundant felsic zeolitic groundmass. Rocks range from a highly mafic chilled marginal facies to medium-grained and porphyritic types with lamprophyric habit. Mafic minerals range from 25 to 80%. Range of modes in 10 sections: analcite, tr-28%; plagioclase (An_{58-68}) and alkali feldspar, 2–24%; titaniferous augite, 11–54%; olivine (serpentine), 0–20%; ores and apatite, 4–14%; groundmass, 15–63%.
P, 14, 1 mile west of Croton Peak Loc. 137 F. S. No. 811AB	Dome-shaped irregular, 0.3 × 0.4 mile, possibly under mass to west	*Analcite syenogabbro.* Gray fine- to medium-grained equigranular aggregate of weathered calcic plagioclase and alkali feldspar(?), fresh subhedral to anhedral purple augite slightly zoned to aegiritic pyroxene and ophitic to plagioclase, serpentine after olivine(?), ore grains, biotite, apatite, and abundant interstitial analcite enclosing discrete grains of pyroxene, biotite, feldspar, and apatite.
P, 14, southwest flank of Croton Peak Loc. 138 F. S. No. 191	Two sills, 5 feet thick, exposed 0.3 mile	*Analcite trachydolerite.* Weathered; has remnants of labradorite (An_{54}), phenocrysts, and interstitial analcite.
O, 14, 3 miles northeast of Burro Mesa Loc. 139 F. S. Nos. 293, 486	Dike, 5 feet thick, exposed sporadically for 3 miles	*Porphyritic analcite basalt.* Black with dense trachytic groundmass composed of labradorite (An_{59}) laths 0.05 to 0.3 mm armored with alkali feldspar, purplish-gray augite anhedral to euhedral 0.01 to 0.1 mm, ore grains slightly smaller than augite, minute apatite needles, minute ragged plates and shreds of biotite, and abundant interstitial analcite. There are rare plagioclase phenocrysts up to 3 × 5 mm, rare discrete grains of alkali feldspar, and a green secondary material possibly derived from olivine.
O, 15, 1 mile south of Croton Peak Loc. 140 F. S. Nos. 224, 483	Sill, 30 feet thick, exposed 1.5 miles in sinuous band in valley with some separate bodies	*Porphyritic analcite basalt.* Dark grayish-green weathered rock with only labradorite phenocrysts (An_{59}), ore grains, analcite, and a trace of biotite unaltered. Interstitial analcite abundant and occurs in clumps with shreds of biotite.
R, 14–16, near north border of area Loc. 141 F. S. Nos. 90, 819	Southern of two dikes, 16 feet thick, exposed 3.5 miles	*Porphyritic analcite basalt.* Dark greenish-gray porphyritic rock with labradorite (An_{52}) phenocrysts up to 3 × 3 mm and smaller augite and olivine(?). Groundmass partly weathered with purple augite grains and prisms, ore grains, and secondary chloritic material. Ocellar structures containing analcite, sodic pyroxene and amphibole, and laths of alkali feldspar are prominent.
R, 14–15, near north border of area Loc. 142 F. S. Nos. 88, 820	Northern of two dikes, 12 feet thick, exposed 3 miles	*Analcite basalt.* Weathered aggregate of labradorite (An_{55}), secondary minerals, and minor interstitial analcite.

TABLE 13.—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
R, 14–17, north boundary of map Loc. 143 F. S. No. 87A	Dike, 8 to 15 feet thick, exposed 6 miles	*Analcite basalt.* Dark gray, fine-grained, subtrachytic seriate aggregate of labradorite (An_{50}) laths (68%), purple augite ophitic to labradorite (11%), olivine and serpentine (9%), ore grains (11%), interstitial analcite (1%), and apatite (tr). Plagioclase laths range up to 0.5 mm with rare phenocrysts; alkali feldspar occurs in small amounts.
R, 16, 1.5 miles north of Paint Gap Hills Loc. 144 F. S. No. 89	Sill(?) remnant, 50 feet thick, capping hill, 0.5 × 0.8 mile	*Porphyritic analcite basalt.* Dark gray to black rock with phenocrysts of labradorite (An_{57}) up to 3 × 3 mm, olivine to 1 × 1 mm, and ore grains to 0.6 × 0.6 mm in groundmass (average grain size 0.08 mm) of labradorite laths, subhedral to euhedral colorless augite, olivine, ore grains (many euhedral), interstitial alkali feldspar, and traces of apatite needles and purplish biotite. Analcite (1%) is colorless, interstitial, and encloses discrete crystals and grains of feldspar, augite, and apatite.
Q, 18, 1 mile west of Grapevine Hills Loc. 145 F. S. No. 292	Sill-like, poorly exposed in alluvium, about 30 feet thick, includes bands of syenite differentiates	*Analcite andesine syenite* (main rock). Altered light gray, fine-grained, seriate rock. Turbid feldspar is largely replaced by fibrous zeolites; it originally included alkali feldspar with cores of andesine ($An_{40?}$) and discrete grains of plagioclase ophitic to scanty light gray clinopyroxene ($2V = 55° \pm$; $nY = 1.697$). Other minerals include biotite ($2V = 18° \pm$), 8%; ore grains, 2%; fat apatite prisms (0.25 mm), tr; interstitial analcite, tr.
F. S. No. 292A		*Analcite syenite* (bands up to 4 inches thick). Light gray, hypautomorphic-granular rock 0.3 to 1 mm. Primarily an aggregate of clear sanidine ($2V = 25° \pm$) and turbid microperthite with about 5% of colorless clinopyroxene zoned to aegirine and altered to brown sodic amphibole, biotite, ore grains, apatite, and minor interstitial analcite.
R, 18, 1.5 miles northwest of Grapevine Hills Loc. 146 F. S. No. 444AC	Tabular, 50 feet thick, exposed 0.5 mile, partly concordant, partly discordant, splits into thin stringers; includes bands of analcite syenite up to 2 inches	*Analcite syenograbbro.* Fine-grained hypautomorphic-granular aggregate of weathered turbid plagioclase and alkali feldspar, deep purple anhedral to euhedral augite partly zoned to gray-green rims, interstitial and ocellar analcite, rods and grains of ore minerals, needles of apatite, shreds of biotite, and brown secondary material possibly derived from olivine. *Analcite syenite* bands. Fine-grained weathered rock with aegirine-augite, interstitial and ocellar analcite, biotite, and apatite.
S, 20, south flank of Rosillos Mountains Loc. 147 F. S. No. 446	Two dikelike masses forming small hill	*Porphyritic analcite olivine diabase.* Fine-grained hypautomorphic-granular groundmass containing abundant labradorite (An_{59}) phenocrysts up to 4 × 5 mm. In the groundmass, deep purple augite ($2V = 45° \pm$) is ophitic to plagioclase laths. Alteration products indicate the former presence of olivine. Interstitial analcite is abundant. Alkali feldspar is present in minor amounts.

Q, 21, near Tornillo Creek Loc. 148 F. S. No. 296ABC	Dikelike mass, irregular up to 30 feet thick	Black to dark gray generally porphyritic rock with considerable variation in texture and composition. Northeast end is *analcite trachydolerite porphyry* with labradorite (An_{57}) phenocrysts to 1×4 mm in a groundmass of andesine (An_{48}) laths (0.2 to 0.5 mm), titaniferous augite, olivine (serpentinized), and ore grains. Phenocrysts and groundmass plagioclase are armored with alkali feldspar; interstitial analcite is sparse and replaces feldspar. Top center and highest point are *analcite alkalic basalt porphyry* with groundmass ranging from dense to an average of about 0.1 mm. Labradorite (An_{56-59}) phenocrysts are as large as 3×8 mm. Abundant interstitial alkali feldspar is present. Olivine (negative, $nZ = 1.728$, $2V = 80° \pm$) occurs in grains up to 1 mm. Augite is restricted to groundmass. Interstitial analcite is sparse and replaces plagioclase.
T, 22, 5 miles north of McKinney Hills Loc. 149 F. S. No. 371	Sill, 30 feet thick, curved outcrop 1 mile long	*Porphyritic analcite diabase.* Gray, medium-grained rock with labradorite (An_{68}) phenocrysts up to 5×7 mm partly albitized and partly replaced by analcite and with inclusions of augite ore grains, brown hornblende, apatite, and biotite. Purplish augite ($nY = 1.705$; $2V = 50° \pm$) is ophitic to groundmass plagioclase and labradorite (An_{51}). Ore grains are intergrown with biotite and in clots with brown secondary material possibly from olivine. Some interstitial alkali feldspar is present. Interstitial analcite with inclusions of apatite is abundant.
K-L, 8, Rattlesnake Mountain (see pp. 257–262; 266–268) Loc. 150	Thick sill or laccolithic intrusion	See pages 175–176.
L, 8, northeast flank of Rattlesnake Mountain Loc. 151 F. S. No. 740	Dike, 4 feet thick, exposed 0.2 mile	*Analcite basalt.* Weathered, originally with olivine. Abundant interstitial and ocellar analcite.
J, 8–9, Peña Mountain (see pp. 263–265; 266–268) Loc. 152	Tabular mass possibly related to Rattlesnake Mountain	See pages 176–177.
J, 8, 0.5 mile southwest of Peña Mountain Loc. 153 F. S. No. 381AD	Tabular, slightly discordant, 50 feet thick, exposed 1 mile	*Analcite diabase.* Dark greenish-gray, fine-grained altered rock with remnants of purple augite, calcic plagioclase and olivine(?) pseudomorphs; interstitial analcite is abundant, analcite also replaces other minerals.
M, 9, 1 mile south of Maverick Mountain Loc. 154 F. S. No. 104	Sill, 20 feet thick, in dipping beds, slightly discordant in places, exposed 0.9 mile	*Analcite trachydolerite.* Dark gray, fine-grained rock with rare phenocrysts of plagioclase up to 2×7 mm, 49%, labradorite (An_{50}) laths average 0.06×0.3 mm, 20%, interstitial alkali feldspar 12%, purple titanaugite ophitic to labradorite 12%, ore minerals 6%, olivine and serpentine 1%, interstitial analcite, and a trace of apatite and biotite.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
M, 9, 1 mile south of Maverick Mountain Loc. 155 F. S. No. 105	Dike, 8 feet thick, exposed 0.5 mile	*Analcite diabase.* Black fine-grained seriate rock with vivid purple augite, ophitic to ragged laths of labradorite (An_{52}) up to 1 mm; ore grains to 0.16 mm; partly serpentinized olivine to 0.6 mm; apatite in needles; analcite mainly turbid interstitial and ocellar. Mode: feldspar, 60%; augite, 19%; olivine and serpentine, 9%; ore grains, 11%; analcite, 1%; apatite, tr.
M, 10, 1 mile south of Maverick Mountain Loc. 156 F. S. No. 179	Remnant of sill 35 feet thick capping small hills	*Analcite syenogabbro* (analyzed specimen). Fine-grained, dark gray, even granular to seriate aggregate of 43%, labradorite (An_{54}) 25%, alkali feldspar 12%, titan-augite 10%, olivine 8%, ore grains and apatite and biotite tr, and analcite 2%. Augite is ophitic to labradorite, olivine is in clusters with ore grains, analcite is interstitial.
M, 9–10, 0.5 mile south of Maverick Mountain Loc. 157 F. S. No. 756BC	Dike, 10 feet thick, exposed intermittently for 0.3 mile	*Analcite basalt.* Weathered aggregate of plagioclase laths, minor alkali feldspar, purple augite ophitic to plagioclase, ore grains, apatite needles, analcite, calcite, and green secondary minerals. Interstitial analcite occurs in veins and vugs and comprises about 5% of the rock. Rare labradorite (An_{60}) phenocrysts are as large as 2×5 mm.
M, 10, 0.5 mile south of Maverick Mountain Loc. 158 F. S. No. 756A	Remnant of sill, 20 feet thick, capping small hill	*Analcite syenogabbro.* Similar to Loc. 156, 0.5 mile south.
N, 10, 1.3 miles east of Maverick Mountain Loc. 159 F. S. Nos. 107, 243	Generally concordant, sill-like, 25 feet thick, exposed irregularly 0.4 mile; margin chilled dense; interior streaked mineralogically and texturally	*Nepheline melasyenite.* Group name for the many varieties of nepheline-bearing rocks in this small area. Rocks range from an aphanitic chilled marginal facies to medium-grained and porphyritic types with lamprophyric habit. Mafic minerals range from 15 to 81 percent. All contain felsic nepheline-rich groundmass and many are extensively zeolitized with fibrous zeolites. Range of modes in 16 sections: nepheline, 1–17%; plagioclase (An_{48-68}), tr-11%; alkali feldspar, 0-tr; analcite, tr-6%; augite, 6–57%; olivine (serpentine), 1–14%; ores, 6–14%; apatite, 1–3%.
M-O, 11, crosses Rough Run Creek Loc. 160 F. S. Nos. 106, 343	Dike, 20 feet thick, exposed sporadically 4.5 miles	*Analcite trachybasalt porphyry.* Dark gray to black rock with phenocrysts of labradorite (An_{59}) up to 9×9 mm and rare microphenocrysts of olivine and ore minerals about 0.3×0.7 mm in a groundmass of minute ore grains, prisms of purple augite, serpentine and labradorite laths 0.01×0.01 mm embedded in grains of alkali feldspar. Analcite replaces plagioclase and is interstitial. This rock is marginal to dense *olivine trachybasalt* without discernible analcite and with very rare phenocrysts.

M, 11, near west flank of Burro Mesa Loc. 161 F. S. Nos. 556, 344	Dike, 20 to 40 feet thick, curved exposure 0.75 mile	*Analcite syenogabbro.* Fine-grained aggregate of plagioclase laths, alkali feldspar grains, purple augite ophitic to plagioclase, olivine, ore grains, apatite, and analcite. Analcite is interstitial and also occurs in pegmatitelike blebs with biotite, sodic amphibole and pyroxene, and alkali feldspar laths.
N, 13, 1 mile northeast Burro Mesa Loc. 162 F. S. No. 67	Irregular sill, 35 feet thick, capping hill	*Analcite basalt.* Rock consists of euhedral to anhedral prismatic gray to purple augite, anhedral plagioclase (An_{64}) laths, anhedral serpentinized olivine, wisps of biotite, needles of apatite, ore grains, and rare acicular hornblende all up to 0.15 mm in a dense clear to turbid groundmass of minute feldspar grains and analcite(?). Mode: plagioclase, 6%; augite, 33%; olivine (serpentine), 6%; ore grains, 4%; biotite, 3%; apatite, 2%; hornblende, tr; groundmass, 46%.
K, 15, east flank of Ward Mountain Loc. 163 F. S. No. 338A	Sill, 10 feet thick, sporadically exposed 0.4 mile	*Analcite basalt porphyry.* Phenocrysts of labradorite (An_{65}) to 3×5 mm and deep violet titanaugite from minute to 2 mm long occur in a turbid weathered groundmass with interstitial analcite. Augite is ophitic to smaller feldspar laths.
D, 12, on bank of Rio Grande Loc. 164 F. S. No. 39A	Dike, 12 feet thick, branching	*Analcite microsyenogabbro.* Black rock with intergranular to subophitic groundmass (0.1 to 0.3 mm) of andesine (An_{42}) laths armored with alkali feldspar, purple anhedral augite, euhedral to anhedral serpentinized olivine, ore grains, smaller flakes of biotite, and needles of apatite. Contains microphenocrysts of plagioclase zoned to An_{60} average 1.5 mm. Analcite is interstitial and in vugs. Mode: alkali feldspar, 9%; plagioclase, 54%; olivine (serpentine), 13%; ores and apatite, 13%; augite, 9%; analcite, 2%; biotite, tr.
D, 14, near Rio Grande Loc. 165. F. S. No. 876AB	Irregular sill-like, 10 to 15 feet thick, exposed 0.5 mile	*Analcite diabase.* Weathered, dark green to black, medium-grained rock, locally porphyritic, with deep purple titanaugite ($Z\Lambda c = 53°$; $2V = 50° \pm$) in slender prismatic crystals slightly ophitic to labradorite (An_{58}), abundant analcite interstitial and in vesicles with calcite and brownish-green secondary minerals.
C, 16, near Rio Grande Loc. 166 F. S. No. 709	Dike, 10 feet thick, exposed 1.5 miles	*Analcite basalt.* Mafic minerals are completely altered; there are remnants of labradorite (An_{54}) phenocrysts and interstitial analcite.
D-E, 17, 4 miles west of Mariscal Mountain Loc. 167 F. S. No. 421	Two dikes, 4 to 10 feet thick, exposed 1 mile; south dike sampled	*Analcite microgabbro.* Fine-grained rock with laths of labradorite, deep purple augite, ore grains, abundant interstitial and ocellar analcite, calcite, and brownish secondary products.
E-G, 17, Cow Heaven Mountain Loc. 168 F. S. No. 44	Sill, 50 to 70 feet thick, with irregular outcrop at flanks of anticline	*Analcite gabbro.* Xenomorphic-granular seriate aggregate of labradorite (An_{67}) to 5×6 mm, grayish-purple titanaugite to 1×3 mm, ore grains to 0.6×0.6 mm, and prominent needles of apatite to 1.3×0.1 mm; interstices between larger grains are filled with a mosaic of alkali feldspar (anorthoclase?) laths, rare aegiritic pyroxene, biotite, hornblende, and obscure secondary materials. Biotite generally accompanies ore grains. Augite is ophitic to plagioclase; plagioclase encloses augite partly altered to biotite, hornblende, and ore grains. Sparse analcite is interstitial; it replaces plagioclase and is ocellar in miarolitic cavities.

TABLE 13.—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
G, 19, 1 mile west of Talley Mountain Loc. 169 F. S. Nos. 529A, 238	Dike, 15 to 20 feet thick, exposed 1.5 miles and cut by gabbro sill	*Analcite syenogabbro.* Dull dark green fine-grained groundmass 0.3 to 0.5 mm with rare labradorite (An_{56}) phenocrysts. Groundmass is composed of alkali feldspar, weathered olivine, and purple augite ophitic to plagioclase; analcite comprises about 5% of the rock.
F, 19, north end of Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 170 F. S. No. 498A	Dike, 8 feet thick, exposed with interruptions 0.4 mile	*Porphyritic analcite basalt.* Dark gray to black rock variable in grain size, maximum 0.1 mm. Phenocrysts and glomerocrysts are olivine ($2V = 85° \pm$, negative) up to 2×3 mm, grayish-purple augite ($Z\Lambda c = 47°0$ to 1.5×2 mm) and labradorite (An_{64}) up to 2×2 mm. Groundmass includes the above minerals, alkali feldspar interstitial and in laths, biotite in minute wisps and flakes, ore minerals, and analcite. Biotite, alkali feldspar, and analcite are concentrated in masses of larger grain sizes, some of which resemble filled miarolitic cavities. Analcite is about 3% of the rock.
E, 19, north end of Mariscal Mountain (see C-F, 27–28, on inset map) Loc. 171 F. S. No. 506	Sill, 25 feet thick	*Analcite gabbro.* Gray medium-grained hypautomorphic-granular rock with average grain size about 3 mm. Anhedral bytownite (An_{78}) zoned to labradorite is albitized and replaced by zeolites. Purple augite euhedral to anhedral ($2V = 40° \pm$) is partly ophitic. Ore grains are rimmed with biotite. Interstitial analcite, clear and turbid, with inclusions of biotite and apatite, comprises about 10% of the rock.
C-D, 20, E, 19, north end of Mariscal Mountain Loc. 172 F. S. Nos. 505, 518, 830	Sill, 25 feet thick	*Analcite gabbro.* Gray medium-grained hypautomorphic-granular seriate aggregate of weathered labradorite (An_{73}) and minor alkali feldspar, abundant subhedral purple augite zoned to sodic rims, ore grains, apatite needles and prisms, shreds of biotite, interstitial analcite, secondary calcite, and chloritic material. Analcite with inclusions of apatite comprises about 4% of the rock.
C, 19, west flank of Mariscal Mountain near Rio Grande Loc. 173 F. S. No. 495	Dike, 8 feet thick, exposed 1 mile	*Analcite basalt.* Weathered aggregate of calcic plagioclase laths and secondary minerals after pyroxene and olivine with interstitial analcite.
G, 21–22, 2 miles east of Talley Mountain Loc. 174 F. S. No. 533	Group of several badly weathered dikes, 2 to 10 feet thick, exposed in area 1×2 miles	*Analcite basalt.* Weathered samples containing relicts of purple labradorite(?) and abundant interstitial analcite.

E, 22, 4.5 miles east of Mariscal Mountain Loc. 175 F. S. Nos. 304A, 294B	Sill, 75 to 100 feet thick, exposed 1 mile; spectacular development of analcite syenite bands in more mafic rock	*Analcite gabbro* is the main rock of the sill; it was not sampled because of degree of weathering. *Analcite syenite.* Light gray hypautomorphic-granular, partly subophitic aggregate (0.3 to 2 mm) of turbid alkali feldspar (orthoclase?) laths (some with andesine (An_{24}) cores), gray-green augite, brown hornblende, biotite, rare ore grains, apatite needles, interstitial analcite, and a trace of zircon. Fibrous zeolites replace feldspar.
F. S. No. 294A		*Spotted analcite syenite.* Rock is ophitic 0.3 to 1 mm but in hand specimen it appears porphyritic. Black irregular "phenocrysts" up to 3×10 mm are actually dark reaction rims around clots of mafic minerals. Rock consists of weathered orthoclase(?), a few labradorite (An_{56}) laths, gray-green augite ophitic to feldspar, ore grains (many rimmed with biotite up to 1 mm), apatite in prisms 0.5 mm in cross section, and analcite. Analcite occurs in interstices and as a replacement of other minerals. Fibrous zeolites and a brown secondary mineral are present. This rock is restricted to a band 10 feet thick.

SYENITE-TRACHYTE (Loc. Nos. 176–249)

Q, 3, 0.75 mile south of Dog Canyon Loc. 176 F. S. No. 752AB	Tabular, slightly discordant, 30 feet thick	*Syenite.* Brownish-gray, medium-grained altered rock originally containing both alkali feldspar and plagioclase; may have been syenodiorite.
Q, 11, west flank of Christmas Mountains (see O, 6 on inset map) Loc. 177 F. S. Nos. 836, 838	One sill, 10 feet thick, exposed 400 feet, and two sills 12 feet thick, exposed 100 feet	*Porphyritic quartz trachyte.* Greenish-gray groundmass composed of alkali feldspar laths average 0.05 mm, completely altered mafic minerals and about 5% interstitial quartz; contains phenocrysts and glomerocrysts of sanidine ($2V = 35° \pm$) up to 5×7 mm and a few masses of altered mafic minerals (?) of phenocryst size; Carlsbad twins are common.
Q, 12, west flank of Christmas Mountains (see O-P, 6–7, on inset map) Loc. 178 F. S. No. 837	Sill, 50 feet thick, forms a ridge	*Porphyritic quartz trachyte.* Similar to Loc. 177 except sanidine is more potassic ($2V = 20° \pm$) and quartz is less abundant.
Q, 12, south edge of Christmas Mountains (See O, 6 on inset map) Loc. 179 F. S. Nos. 404, 403	Two sills, 15 to 20 feet thick, exposed 0.1 mile and 0.2 mile	*Trachyte.* Light to dark gray, amygdaloidal rock with a dense groundmass of laths of alkali feldspar about 0.1 mm, turbid brown faintly polarizing interstitial material, ore grains, and apatite. Phenocrysts and microphenocrysts up to 3×6 mm are of andesine to labradorite (An_{51}) and green to brownish clinopyroxene (+; $2V = 50° \pm$; $Z \wedge c = 38°$). Rock is transitional to trachyandesite.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
P, 12, in pass between Christmas and Little Christmas Mountains (see O, 7, on inset map) Loc. 180 F. S. Nos. 340A (405A, 100B), 405B, 405C	Four dikes, 15 to 20 feet thick	A. *Trachyte.* Weathered greenish-gray rock. The felty groundmass is composed of turbid weathered feldspar phenocrysts up to 3 × 4 mm and minute prisms of green ferromagnesian mineral. B. and C. *Porphyritic quartz sodic trachyte.* Greenish-gray rock with phenocrysts of sanidine (2V = 35° ±) up to 4 × 8 mm in a subtrachytic groundmass of alkali feldspar laths about 0.1 mm and aegiritic pyroxene and riebeckite laths with quartz in discrete grains. Analyzed specimen—quartz, 1%; feldspar, 86%; pyroxene, 2%; riebeckite, 11%; ore minerals, fluorite, and apatite, tr. D. *Trachyte.* Dark green microcrystalline groundmass with phenocrysts and glomerocrysts of plagioclase (An_{35}) up to 3 × 3 mm.
P-R, 12, Q-R, 13, southeast flank of Christmas Mountains (see O-P, 7, N-Q, 8, O-R, 9, Q-R, 10, on inset map) Loc. 181 F. S. Nos. 77, 79, 85, 93BC, 98, 340B, 717, 720, 721, 720A	Assemblage of tabular bodies, thickness 10 to 450 feet, with considerable variation in individual masses; generally concordant but locally discordant	*Porphyritic quartz sodic microsyenite.* Most specimens weathered; group identification and description are from a few relatively fresh samples. Gray to grayish-green fine-grained rock with feldspar phenocrysts to 5 × 5 mm. Groundmass is subtrachytic with alkali feldspar laths (Carlsbad twins sanidine-anorthoclase?) in most specimens about 0.3 mm. Feldspar phenocrysts are sanidine-anorthoclase (2V = 50° ±) along with a few microperthitic and/or albitized crystals. A few phenocrysts have oligoclase cores. Mafic minerals include larger greenish-gray augite (up to 2 mm) zoned to aegiritic pyroxene, some mantled with sodic amphibole, and small (average 0.03 mm) crystals and grains of pyroxene (aegirine and aegirine-augite) and sodic amphibole (arfvedsonite and/or riebeckite), many as inclusions in feldspar. Magnetite grains are up to 0.1 mm; smaller ones occur as inclusions in pyroxene. Quartz is mainly interstitial poikilitic to feldspar tr to 2%; apatite tr. Estimated mode one specimen: feldspar, 87%; pyroxene, 6%; amphibole, 2%; quartz, 2%; ores, 2%.
P, 12, 1 mile east of Little Christmas Mountain (see N, 8, on inset map) Loc. 182 F. S. No. 94	Sill, 25 to 30 feet thick, exposed 0.3 mile	*Porphyritic augite trachyte* transitional to *trachyandesite.* Greenish-gray orthophyric seriate groundmass (0.08 to 0.2 mm) with phenocrysts and glomerocrysts of plagioclase, augite, and altered olivine up to 3 × 3 mm. Plagioclase is zoned (average An_{42}) in phenocrysts and groundmass and mantled with alkali feldspar. Groundmass feldspar is mainly untwinned sanidine-anorthoclase. Larger pyroxene is prismatic subhedral lavender-gray augite (ZAc = 41°; 2V = 55° ±); smaller pyroxene is greenish-gray slightly zoned aegiritic augite mainly as inclusions in feldspar. Grains of olivine are enclosed in brown alteration products. Magnetite occurs as anhedral to euhedral inclusions in all other minerals; apatite and quartz occur as traces. Estimated mode: plagioclase, 20%; sanidine-anorthoclase, 60%; augite, 13%; magnetite, 6%; olivine, 1%.

P-Q, 12, 1 mile east of Little Christmas Mountain (see N-O, 8–9, on inset map) Loc. 183 F. S. No. 93A	Discordant, pluglike, 0.9 × 0.3 mile	*Porphyritic quartz sodic microsyenite.* Similar to Loc. 181.
Q, 12, southeast flank, Christmas Mountains (see O, 9, on inset map) Loc. 184 F. S. No. 92A	Dike, 30 feet thick, exposed 0.2 mile	*Porphyritic quartz microsyenite.* Gray fine-grained (average 0.5 mm) hypautomorphic-granular rock with feldspar phenocrysts and glomerocrysts up to 4 × 4 mm. Feldspar phenocrysts are turbid weathered oligoclase and microperthite; some are mantled with alkali feldspar. Groundmass feldspar is composed about equally of laths of oligoclase mantled with alkali feldspar and anhedral to subhedral sanidine ($2V = 20° \pm$) mainly untwinned. Mafic minerals (about 10%) include green slightly pleochroic slender prismatic (up to 1.8 mm) augite ($Z\Lambda c = 45°$) partly zoned to aegiritic pyroxene and partly replaced by sodic amphibole, sodic amphibole anhedral up to 0.3 mm (arfvedsonite? $X\Lambda c = 16°$), and minute prisms and needles of bright green aegiritic pyroxene. Minute ore grains occur mainly as inclusions in pyroxene; trace apatite. Quartz (1%) is in discrete grains; there is a trace of micropegmatite.
Q, 13, near Cub Spring (see Q, 10, on inset map) Loc. 185 F. S. No. 718	Dike, 2 to 20 feet thick, exposed 0.5 mile	*Porphyritic quartz sodic microsyenite.* Similar to Loc. 181.
Q, 13, east flank of Christmas Mountains (see Q-R, 10, on inset map) Loc. 186 F. S. No. 926A	Dike, 10 to 12 feet thick, exposed 0.3 mile	*Porphyritic quartz microsyenite.* Brownish-gray, subtrachytic groundmass of alkali feldspar contains laths which average 0.2 mm, brown turbid interstitial material, biotite books to 1 mm long, about 3% quartz grains about 0.15 mm poikilitic to feldspar, ore grains partly derived from resorption of biotite and a trace of apatite and zircon; phenocrysts and glomerocrysts are oligoclase (An_{28}) to 4 × 6 mm.
R, 13, east of Christmas Mountains (see R-S, 11–12, on inset map) Loc. 187 F. S. No. 821	Irregular discontinuous dikelike mass, 15 to 40 feet thick, exposed 0.6 mile	*Porphyritic trachyte.* Grayish-green rock with prominent spheroidal weathering. Trachytic groundmass consists of alkali feldspar laths, average 0.1 mm, ragged prismatic grains of brown hornblende ($Z\Lambda c = 19°$), minute grains of green aegiritic pyroxene, ore minerals, and about 1% interstitial quartz. Phenocrysts and glomerocrysts are sanidine-anorthoclase(?), many with plagioclase (An_{32}) cores up to 5 × 5 mm and greenish-gray augite ($Z\Lambda c = 42°$) up to 0.3 × 3 mm. Total mafic minerals comprise about 5% of the rock .
R, 13 east of Christmas Mountains (see R, 11, on inset map) Loc. 188 F. S. No. 822	Four hill-capping remnants of concordant tabular mass, 20 feet thick	*Porphyritic quartz microsyenite.* Greenish-gray weathered rock, probably the same as Loc. 181 except with fewer phenocrysts.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
R, 13, 0.5 mile east of Christmas Mountains (see R, 11, on inset map) Loc. 189 F. S. No. 82	Sill-like, 50 feet thick, exposed 0.6 mile	*Porphyritic quartz sodic microsyenite.* Light gray, brown-weathering rock with subtrachytic groundmass of alkali feldspar about 0.2 mm, about 3% of anhedral quartz partly poikilitic to feldspar, completely altered sodic ferromagnesian mineral and ore grains to 0.3 mm, apatite needles, and phenocrysts of sanidine-anorthoclase to 4 × 5 mm.
Q, 13, 2 miles southeast of northwest corner of area (see R, 12, on inset map) Loc. 190 F. S. No. 914I	Tabular, partly discordant, 6 to 8 feet thick, immediately above a basaltic mass	*Quartz trachyte porphyry.* Brown weathered subtrachytic groundmass of alkali feldspar laths with Carlsbad twins, anhedral quartz grains, interstitial brown secondary material (mainly from weathering of mafic minerals), and altered ore grains containing shattered phenocrysts and glomerocrysts of sanidine ($2V = 30° \pm$) up to 5 × 5 mm, some with Carlsbad twins. Some phenocrysts contain oligoclase(?) cores and there are a few discrete phenocrysts of oligoclase.
Q, 13, east of Christmas Mountains (see Q, 10–11, on inset map) Loc. 191 F. S. Nos. 823, 824, 824A	Tabular, 35 feet thick, exposed 0.6 mile. Probably related to mass Loc. 201	*Quartz microsyenite.* Similar to Loc. 201.
Q, 13, east of Christmas Mountains (see Q, 11, on inset map) Loc. 192 F. S. Nos. 914ABD, 825	Three sills, 3 to 8 feet thick, in canyon wall exposed 0.4 mile	*Quartz microsyenite.* North and south sills similar to mass Loc. 201, except somewhat finer grained and more weathered. Center sill has dense microcrystalline groundmass and phenocrysts of alkali feldspar and oligoclase(?).
Q, 13, 2.5 miles south of northwest corner of map (see Q, 11, on inset map) Loc. 193 F. S. No. 74, 710D	Tabular mass, 60 feet thick, exposed 0.5 mile, related to Loc. 191	*Quartz microsyenite.* Brown weathered hypautomorphic-granular seriate rock 0.05 to 1 mm with rare phenocrysts of oligoclase (An_{25}) rimmed with sanidine to 5 mm. Untwinned sanidine occurs in many stubby quadratic crystals ($2V = 35° \pm$). Mafic minerals are completely altered to limonite. About 3% quartz occurs as interstitial grains and micropegmatite. There is a trace of acicular apatite.
P-Q, 11, west boundary of map Loc. 194 F. S. No. 402	Tabular, sill-like, 100 feet thick, irregular exposure, 0.5 mile long	*Porphyritic quartz sodic microsyenite.* Similar to Loc. 181, larger mafic minerals completely weathered.

P, 12, Little Christmas Mountain Loc. 195 F. S. Nos. 99ABC, 270	Discordant, pluglike, 1 × 1.5 miles	*Porphyritic quartz aegirine-augite trachyte.* Varies in composition, locally approaches rhyolite. Rock consists of a green to brownish-green dense felty trachytic groundmass with alkali feldspar laths about 0.05 mm, prisms of aegirine-augite and feldspar. Phenocrysts are sanidine ($2V + 30° \pm$) up to metallic grains about 0.03 mm and about 8% of interstitial quartz poikilitic to 3 × 1 mm with Carlsbad twins and aegirine-augite slightly smaller.
P, 12–13, 0.5 mile northwest of Slickrock Mountain Loc. 196 F. S. No. 96	Sill, 18 feet thick, exposed 0.6 mile	*Quartz trachyte.* Weathered light brown hypautomorphic-granular aggregate of alkali feldspar laths, mostly Carlsbad twins, average length 0.05 mm, about 6% interstitial quartz, abundant weathered mafic minerals, and a few phenocrysts and glomerocrysts of zoned plagioclase, average An_{35}.
N-P, 12–13, flanking north end of Burro Mesa Loc. 197 F. S. Nos. 68, 458C, 852ABC, 854A, 859, 887	A group of sills branching and uniting 15 to 50 feet thick, exposed 3 miles along east flank of anticline and in small exposure in O, 13	*Andesine trachyte.* Weathered greenish-brown rock with groundmass of alkali feldspar, about 10% of completely weathered mafic minerals, and trace to 1% of quartz; average grain size is 0.08 mm with about 5% andesine (An_{40}?) phenocrysts and glomerocrysts up to 3 × 3 mm with rare longer laths. Samples vary in grain size and amount of plagioclase.
N, 13, flanking north end of Burro Mesa Loc. 198 F. S. No. 885	Sill, 6 feet thick, possibly offshoot from mass Loc. 197, exposed 0.3 mile	*Trachyte.* Weathered brownish-gray felty subtrachytic aggregate of alkali feldspar laths, average about 0.1 mm, with rare microphenocrysts to 1 mm of sanidine-anorthoclase ($2V = 45° \pm$) and indeterminate plagioclase along with about 8% of completely weathered mafic minerals and a trace of interstitial quartz. Sample from southwest flank contains quartz 1%, feldspar 82%, pyroxene 6%, amphibole 5%, olivine 2%, magnetite, tr. A sample near the north contact side is a felty aggregate of feldspar laths with minute prisms of aegiritic pyroxene.
N, 12, north end of Burro Mesa in fault zone Loc. 199 F. S. No. 739B	Two discordant masses, 20 feet thick, exposed about 100 feet	*Alkalic leucotrachyte.* White trachytic matrix of alkali feldspar laths with Carlsbad twins, average length about 0.05 mm, about 1% weathered mafic minerals in minute grains, and a trace of interstitial quartz. There are sporadic phenocrysts up to 1.5 × 5 mm of sanidine-anorthoclase ($2V = 40° \pm$) in Carlsbad twins with quadratic cross section.
O, 14, south flank of Slickrock Mountain Loc. 200 F. S. No. 814	Two dikes, 5 feet thick, exposed 200 feet	*Alkalic quartz microsyenite.* Brownish-gray xenomorphic-granular seriate rock 0.04 to 0.5 mm with rare euhedral untwinned sanidine crystals with quadratic cross section ($2V = 25° \pm$) and rare weathered feldspar phenocrysts. Generally the rock is an aggregate of sanidine grains and laths, a few with altered plagioclase cores, about 10% completely weathered mafic minerals, about 1% quartz in discrete grains, and a trace of apatite.
O-Q, 13–14, east of Christmas Mountains Loc. 201 F. S. Nos. 75B, 188, 223 (623), 812, 860C-K, 274B, 826	Truncated laccolithic mass 30 to 400 feet thick, exposed 3.5 miles	*Quartz microsyenite.* Gray to greenish-gray hypautomorphic-granular seriate (0.09 to 1 mm) aggregate of sanidine-anorthoclase, and weathered mafic minerals with 1 to 5% of interstitial quartz. Rare larger feldspar crystals (2 × 4 mm) are partly microperthitic; anorthoclase ($2V = 40° \pm$, rarely $2V = 20° \pm$) untwinned quadratic, and partly microperthitic oligoclase rimmed with alkali feldspar. Weathered mafic minerals, about 12%, include rare unaltered grains of augitic clinopyroxene.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
P, 13, north flank of Slickrock Mountain Loc. 202 F. S. Nos. 860AB	Bands to 8 inches thick in analcite andesine syenite	*Quartz microsyenite.* Light gray xenomorphic-granular aggregate of anhedral microperthite and orthoclase, some subhedral sanidine-anorthoclase, about 5% ore grains and altered ferromagnesian minerals, 3% interstitial quartz, and a trace of zircon and apatite.
R, 13, 1 mile south of north boundary of map Loc. 203 F. S. No. 716	Dike, 20 feet thick, exposed 0.5 mile	*Alkalic quartz microsyenite.* Light gray generally xenomorphic-granular seriate rock, average grain size 0.3 mm, with a few euhedral to subhedral sanidine crystals and rare feldspar phenocrysts up to 1.5 × 2.5 mm. A mesostasis of microlitic alkali feldspar is mostly continuous with sanidine grains or crystals. Feldspar is mainly untwinned sanidine ($2V = 25° \pm$). Phenocrysts are microperthitic, some with homogeneous alkali feldspar rims. Mafic minerals, about 12%, are completely altered. Quartz, about 1%, occurs in discrete grains. There is a trace of apatite.
O, 14, 4 miles northeast of Burro Mesa Loc. 204 F. S. No. 484	Bands a few inches thick in syenodiorite mass	*Alkalic syenite.* Light gray hypautomorphic-granular seriate rock up to 1.5 mm consisting of an aggregate of anorthoclase laths (Carlsbad twins: $2V = 45° \pm$), about 8% biotite flakes and wisps to 0.5 mm, a trace of green aegirine grains to 0.1 mm, a trace of ore grains, and interstitial calcite.
S, 18, south flank, Rosillos Mountains near north boundary of area Loc. 205 F. S. No. 445	Dike, 5 feet thick, exposed 0.1 mile in arroyo	*Quartz microsyenite.* Weathered lavender fine-grained aggregate of alkali feldspar (some microperthite), completely altered mafic minerals, interstitial quartz, and secondary quartz with a trace of apatite and zircon.
P, 19–20, southeast flank of Grapevine Hills Loc. 206 F. S. No. 56	Sill, 75 feet thick, faulted, exposed 2 miles on structure of Grapevine Hills	*Riebeckite trachyte.* Light greenish-gray rock with clots of coarser ferromagnesian minerals and feldspar to 1 cm. Texture is trachytic with laths of alkali feldspar 0.04 to 0.2 mm. There are abundant shreds and grains of riebeckite to 0.4 mm, minor aegirine-augite, and a trace of fluorite and quartz.
O, 19, 1 mile northeast of Lone Mountain Loc. 207 F. S. Nos. 55, 341	Dike, 15 feet thick, exposed 0.5 mile	*Quartz trachyte.* Gray, fine to aphanitic, weathered aggregate of alkali feldspar laths (average about 0.1 mm) with about 10% of completely weathered mafic minerals and about 1% of interstitial quartz. Weathered feldspar phenocrysts are rare.
N-Q, 22–23, between Tornillo Creek and McKinney Hills Loc. 208 F. S. Nos. 550, 906, 907, 908	Twenty-odd dikes and sills, 1.5 to 6 feet thick, mainly exposed about 0.1 mile	*Trachyte.* Weathered basaltic, trachytic, and rhyolitic masses. Only the general nature is determinable.

N-Q, 22–24, McKinney Hills laccolith (see pp. 248–253) Loc. 209	Faulted laccolith	See pages 186–188.
K, 5, west of Sierra Aguja Loc. 210 F. S. Nos. 713, 846	Bands and lenses to 1.5 feet thick in olivine gabbro mass	*Syenite.* Light gray weathered hypautomorphic-granular seriate (minute to 1.5 mm) aggregate of stubby sanidine-anorthoclase laths, many with albite (An_6) cores, about 5% of gray clinopyroxene enclosed in feldspar and present partly as skeleton crystals, brown hornblende ($Z \wedge c = 23°$), about 1% interstitial quartz, ore grains, and traces of apatite.
N, 9–10, Maverick Mountain Loc. 211 F. S. No. 931	Laccolithic mountain, 1 × 1.5 miles	*Sodic trachyte.* Dark gray porphyritic rock with anorthoclase ($2V = 50° \pm$) phenocrysts and glomerocrysts average 3 × 4 mm and aegirine-augite 0.4 × 1.5 mm. Groundmass is composed of trachytic sodic orthoclase, Carlsbad twins 0.1 × 0.4 mm, and minor equidimensional anorthoclase interleaved with green aegirine-augite and minor arfvedsonite, riebeckite, ore grains, and interstitial quartz. Mode: quartz, 0.6%; feldspar, 78.8%; aegirine-augite, 20.6%; riebeckite, arfvedsonite, and iron ore, tr. (Lonsdale, 1940, pp. 1582–1583.)
N-O, 9–10, Indian Head Mountain, immediately north of Maverick Mountain Loc. 212 F. S. Nos. 28A, 944	Sheetlike, irregularly discordant	*Sodic trachyte.* Generally similar to the rock of Maverick Mountain.
N, 12, north end of Burro Mesa Loc. 213 F. S. No. 677	Plug, 0.1 mile in diameter	*Trachyte.* Light yellowish-gray fine-grained felty aggregate of altered alkali feldspar laths and altered mafic minerals—average grain size 0.1 mm along with larger altered grains of mafic minerals.
N, 12, north end of Burro Mesa Loc. 214 F. S. No. 591	Plug, 0.2 mile in diameter, vertically sheeted, in lava	*Trachyte porphyry.* Light gray rock with abundant feldspar phenocrysts up to 0.5 to 1.3 mm, trachytic groundmass of alkali feldspar microlites with Carlsbad twinning average 0.05 mm long, ragged flakes and grains of partly altered amphibole(?) and ore grains. Feldspar phenocrysts are anorthoclase laths with quadratic cross section and Carlsbad twins ($2V = 45° \pm$). Altered mafic and ore grains are about 0.4 mm. There is a trace of dusty apatite. One amphibole microlite 0.04 × 2.7 mm is studded with minute ore grains.
N, 12, north of highway, north end of Burro Mesa Loc. 215 F. S. No. 180	Discordant, pluglike, 0.1 × 0.3 mile	*Trachyte.* Greenish-gray trachytic hypautomorphic-granular (0.03 to 0.3 mm) rock with feldspar microphenocrysts up to 0.3 mm. Groundmass consists of laths of alkali feldspar, many with oligoclase(?) cores, and anorthoclase ($2V = 50° \pm$). Mafic minerals (about 10%) are altered to limonitic material. A few partly altered grains are aegiritic(?) pyroxene and biotite(?).

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
L, 12, western part of Burro Mesa Loc. 216 F. S. Nos. 62AB	Plug, 0.5 mile in diameter, surrounded by steeply dipping Tertiary beds	*Alkalic trachyte.* Similar to mass Loc. 215 except trachytic texture is less pronounced, Carlsbad twinning less prominent, and partly altered olivine is present.
L, 12, western part of Burro Mesa Loc. 217 F. S. No. 61AB	Plug, 0.5 mile in diameter, concentrically sheeted, surrounded by steeply dipping Tertiary beds	*Alkalic trachyte.* Gray weathering brownish rock—essentially a seriate trachytic aggregate of alkali feldspar laths ranging from 0.05 to 1 mm in length with the bulk in aphanitic range, with a few percent of interstitial quartz and 10 to 15% of mafic minerals. Feldspar laths show Carlsbad twinning and larger crystals have $2V = 40° \pm$; all are sanidine-anorthoclase. Very rare phenocrysts appear to have the same composition. Mafic minerals ranging from minute to 0.6×0.8 mm include green clinopyroxene augite(?) ($Z \wedge c = 49°$; $2V = 55° \pm, +$), intergrown with amphibole and also partly or completely resorbed to magnetite. Amphibole, brown to green hornblende ($Z \wedge c = 14°$), occurs as reaction product from pyroxene and in discrete grains. Analyzed specimen: quartz 3%, feldspar 85%, augite 4%, hornblende 1%, magnetite 7%, apatite and zircon, tr. Some magnetite probably formed from resorption of olivine.
M-N, 14, 2 miles east of Burro Mesa Loc. 218 F. S. No. 398	Discordant, pluglike, 0.2 mile long	*Trachyte porphyry.* Rock consists of a reddish-brown aphanitic feldspathic groundmass (average grain size 0.01 mm) with dustlike altered mafic minerals and possibly minor interstitial quartz in which are phenocrysts and glomerocrysts of feldspar, minor magnetite, and altered mafic minerals up to 5×5 mm. Feldspar phenocrysts include andesine, zoned An_{32-38}, some as cores in orthoclase(?) and discrete crystals of orthoclase(?). Traces of apatite and zircon are present.
N, 14, 3 miles east of Burro Mesa Loc. 219 F. S. No. 52	Sill, 25 feet thick, exposed 1 mile along dip slope	*Quartz microsyenite.* Dove-gray orthophyric aggregate of untwinned orthoclase 0.2 to 0.5 mm and abundant weathered brown mafic minerals with a few phenocrysts of weathered andesine (An_{40}). There is about 1% interstitial quartz. Rock is somewhat amygdaloidal with quartz and limonite fillings.
N, 14, near highway Loc. 220 F. S. No. 722	Sill-like, 40 feet thick, exposed 0.3 mile	*Quartz trachyte.* Gray orthophyric aggregate of alkali feldspar grains average about 0.08 mm with about 4% interstitial quartz and 5% weathered mafic minerals, some of phenocryst size. Rare phenocrysts and glomerocrysts are oligoclase(?) to 2×2 mm, some mantled with alkali feldspar.
L, 16, north flank of Casa Grande Loc. 221 F. S. No. 669	Dikelike mass, maximum thickness 75 feet, exposed 0.4 mile	*Trachyte.* Greenish rock with felty feldspathic microcrystalline groundmass containing abundant plumose and spongy grains of completely altered mafic minerals and a few sanidine phenocrysts ($2V = 30° \pm$) with Carlsbad twins and quadratic cross sections up to 0.5×5 mm.

L, 16–17, "Chinese Wall" cuts northeast flank of Casa Grande Loc. 222 F. S. No. 192AB	Dike, 20 to 50 feet thick, vertical with inclusions of foreign rock, exposed 0.8 mile	*Sodic trachyte.* Dense felty aggregate of alkali feldspar laths about 0.1 mm long with about 20% aegiritic pyroxene and ore grains (average 0.03 mm) with a few phenocrysts of sanidine-anorthoclase up to 2 mm long.
L, 17, northeast flank of Casa Grande Loc. 223 F. S. No. 913ABC	Three dikes, 8 to 25 feet thick, exposed on slope	(1) *Quartz trachyte.* Light gray to white dense felty aggregate of alkali feldspar, a few larger grains of quartz about 0.05 mm and minute grains of completely weathered mafic minerals. (2) *Quartz trachyte.* Light gray to pink trachytic groundmass of weathered alkali feldspar laths average about 0.08 mm long, containing a ferromagnesian mineral completely altered to limonitic material, and quartz grains with a few phenocrysts and glomerocrysts of weathered orthoclase(?) up to 2 × 2 mm. (3) *Trachyte.* Dove-gray dense felty weathered aggregate of alkali feldspar and ferromagnesian mineral (with habit of riebeckite) with a few phenocrysts and weathered alkali feldspar 0.5 × 2 mm.
L, 17, 1 mile east of Casa Grande Loc. 224 F. S. No. 667ABC	Four dikes, 10 to 50 feet thick, cutting lava	(1) "Easternmost." *Porphyritic trachyte.* Greenish-gray rock with a microcrystalline matrix containing abundant sanidine ($2V = 25° \pm$) phenocrysts and glomerocrysts with Carlsbad twins up to 3 × 3 mm. (2) Two hundred yards west of (1). *Trachyte.* Rock consists of a gray dense trachytic groundmass with alkali feldspar laths and altered mafic minerals average grain size 0.05 mm; trace interstitial quartz. (3) Forty feet west of (2). *Porphyritic riebeckite trachyte.* Dark green rock with trachytic groundmass composed of alkali feldspar laths average about 0.1 and about 12% smaller prismatic grains of riebeckite with microphenocrysts of riebeckite and magnetite to 0.4 and sanidine ($2V = 30° \pm$) with Carlsbad twins up to 2 × 5 mm. There is about 1% of interstitial quartz. (4) Fifty yards west of (3). *Trachyte.* Similar to (2).
N-O, 16–17, Government Spring laccolith Loc. 225 F. S. Nos. 49, 391, 392, 435	Laccolith, 1 × 2 miles	*Quartz microsyenite.* Light gray to dark gray rock with considerable variation in texture. Generally it is hypautomorphic-granular seriate and slightly porphyritic with rare glomerocrysts to 5 mm. The rock is an aggregate of sanidine-anorthoclase tablets, some with microperthitic borders, oligoclase (An_{22}) but also zoned and armored with alkali feldspar, brown to green augite ($Z \wedge c = 50°$; $2V = 50° \pm$), quartz, ore grains, apatite, zircon, and fluorite. Interstitial micropegmatite is rare. Quartz is variable—2 to 8%.
N-M, 18, southwest flank of Panther laccolith Loc. 226 F. S. No. 659AB	Two dikes, 12 feet thick, exposed 300 feet	*Sodic trachyte.* Weathered trachytic aggregate of alkali feldspar and riebeckite and/or arfvedsonite with trace to 0.5% quartz. In western dike feldspar laths are up to 0.2 mm, in eastern 0.1 mm. Mafic minerals are about 0.4 mm.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
L, 17–18, near head of Pine Canyon Loc. 227 F. S. No. 661A	Dike, 15 feet thick, exposed 0.2 mile	*Quartz trachyte.* Lavender-gray weathered trachytic aggregate of alkali feldspar laths and altered mafic minerals average 0.1 mm and about 1% quartz along with larger grains of completely altered mafic minerals.
K, 18, southwest flank of Crown Mountain Loc. 228 F. S. No. 663AB	Pluglike with obscure relations, 0.3 mile in diameter	*Porphyritic trachyte.* Weathered rock consists of an aphanitic groundmass with sparse microphenocrysts to 0.5 mm of weathered alkali feldspar.
L, 18, 1 mile south of Pummel Peak Loc. 229 F. S. No. 684ACD	Irregular, discordant, exposed 0.6 mile	*Sodic trachyte.* Dark green dense trachytic rock with alkali feldspar laths average 0.1 mm, riebeckite and aegiritic pyroxene average 0.05 mm along with rare weathered feldspar phenocrysts up to 0.8 mm and green augite up to 0.4 mm. There is a trace of interstitial quartz.
M, 19, 0.5 mile south of Pummel Peak Loc. 230 F. S. No. 684B	Irregular, discordant, pluglike, 400 feet in diameter	*Riebeckite quartz trachyte.* Dark grayish-green dense trachytic groundmass of alkali feldspar and mafic microlites with microphenocrysts of riebeckite up to 0.2×0.3 mm and rare phenocrysts of weathered alkali feldspar up to 1×2 mm. Interstitial quartz is about 3%.
M, 18–19, 0.3 mile south of Pummel Peak Loc. 231 F. S. No. 684	Discordant, outcrop elongate 0.6×0.2 mile, stocklike	*Quartz sodic trachyte.* Green dense felty aggregate of alkali feldspar laths and needles, minute prismatic grains of sodic pyroxene and sparse grains of quartz with a few phenocrysts of microperthite to 2 mm and anhedral microphenocrysts of riebeckite with vivid blue and green pleochroism. Microphenocrysts of aegirine-augite are rare.
M, 18–19, south of Pummel Peak Loc. 232 F. S. No. 27	Dike, 5 feet thick, exposed 0.5 mile	*Porphyritic riebeckite trachyte.* Groundmass is a felty aggregate of alkali feldspar laths and needles. There are abundant tufts and grains of weathered riebeckite, rare weathered phenocrysts of alkali feldspar up to 4 mm, traces of quartz and aegirine. Ore grains formed probably from alteration of ferromagnesian minerals.
L-M, 19, 1 mile southeast of Pummel Peak Loc. 233 F. S. No. 686HK	Irregular, poorly exposed, discordant	*Sodic trachyte.* Dark gray dense weathered trachytic rock containing abundant mostly weathered riebeckite. There is a trace of interstitial quartz.
H, 19–20, 2.5 miles west of Chilicotal Mountain Loc. 234 F. S. Nos. 170, 171	Four separate tabular masses, about 20 feet thick, surrounded by alluvium, probably remnants of a sill	*Alkalic quartz microsyenite.* Gray trachytic aggregate of weathered alkali feldspar laths 0.2 to 0.6 mm, completely weathered mafic minerals about 6% and a few percent of interstitial quartz with rare weathered alkali feldspar phenocrysts up to 2 mm long.

J, 20, 1 mile west of Chilicotal Mountain Loc. 235 F. S. No. 362	Sill(?), about 15 feet thick	*Alkalic quartz microsyenite.* Gray, weathered, similar to rock in Chilicotal Mountain, except finer grained and with less quartz.
J, 20, at northwest flank of Chilicotal Mountain Loc. 236 F. S. Nos. 172, 363	Sill, 20 feet thick	*Alkalic quartz microsyenite.* Similar to rock in Chilicotal Mountain except finer grained and with less quartz.
K, 20, 1.5 miles south of Nugent Mountain Loc. 237 F. S. No. 173	Tabular, generally concordant, about 50 feet thick	*Quartz microsyenite.* Gray weathered hypautomorphic-granular seriate rock from 0.08 to 0.8 mm with a few phenocrysts. Feldspar and mafic minerals are completely weathered; there is about 1% quartz in discrete grains.
H-K, 20–21, Chilicotal Mountain Loc. 238 F. S. Nos. 360AB, 361, 415, C33	Tabular mass, generally concordant, 40 to 200 feet thick, dips northeast, thinnest at south end and southeast flank	*Alkalic quartz microsyenite.* Light gray subtrachytic rock, weathering to reddish brown, with Carlsbad twins of sanidine-anorthoclase ($2V = 40° \pm$) averaging about 0.4 mm long, about 8% completely weathered mafic minerals and about 1 to 5% interstitial quartz and in some specimens a trace of micropegmatite. Weathered feldspar phenocrysts up to 4×6 mm are rare.
H, 21, southern end of Chilicotal Mountain Loc. 239 F. S. No. 358B	Three dike masses cutting basic rock, one 100 feet thick, exposed 0.8 mile, others shorter	*Spherulitic quartz microsyenite.* Rock consists of laths of alkali feldspar including microperthite with Carlsbad twins about 0.4 mm long in spherulites or subparallel groups along with completely weathered mafic minerals and a few percent of interstitial quartz.
K, 22, near Boquillas-Hot Springs road Loc. 240 F. S. Nos. 287, 797	Plug-shaped mass 0.1 mile in diameter forming black hill 60 feet high, contacts concealed, and dike 40 feet thick exposed 0.3 mile in arroyo wall	*Quartz microsyenite.* Gray hypautomorphic-granular seriate rock with grain size ranging from minute to 2 mm; euhedral constituents are minor. Anorthoclase ($2V = 45° \pm$) is anhedral to euhedral, larger grains have oligoclase cores; some show Carlsbad twins. Completely altered pyroxene comprises approximately 15% of the rock. Interstitial quartz is about 5%. There is a trace of apatite.
H, 26, on Rio Grande near Hot Springs Loc. 241 F. S. No. 9	Sill, 3.5 feet thick, exposed 300 feet on river bank	*Quartz trachyte.* Light gray to white rock which weathers brown composed of a trachytic to felty aggregate of alkali feldspar laths average 0.035 mm with about 1% quartz in discrete grains and about 1% weathered mafic minerals.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
G, 8, 2 miles northwest of Castolon Loc. 242	Bands 6 to 8 inches thick in syenodiorite mass	*Alkalic syenite.* Light gray hypautomorphic-granular seriate (minute to 2 mm) aggregate of about 90% feldspar and 10% mafic minerals. Feldspar includes about equal quantities of turbid albite (An_2) invariably as cores rimmed by sanidine ($2V = 20° \pm$) and discrete untwinned grains and crystals of sanidine; some of the latter are euhedral with quadratic cross sections; some show slight unmixing along margins with formation of microperthite. Mafic minerals include gray clinopyroxene (augite?; $Z \wedge c = 43°$; $2V = 50° \pm$) in stubby to slender prismatic grains and crystals zoned to green sodic pyroxene and also intergrown with brown hornblende ($Z \wedge c = 25°$; 2V large) which is present also in discrete grains; ore minerals are present in rods and plates; there are traces of interstitial chalcedony(?) and needles of apatite.
G, 14–15, 1.5 miles west of Dominguez Mountain Loc. 243 F. S. No. 621	Dike, 25 feet thick, exposed 0.3 mile	*Porphyritic trachyte.* Gray weathered rock composed of a dense feldspathic matrix and phenocrysts of alkali feldspar and mafic minerals 0.5 to 4 mm.
F-G, 15–16, Dominguez Mountain mass and dike swarm extending southwestward into D, 12 (see pp. 257–265; 269–270) Loc. 244	Dike swarm southwest of Dominguez Mountain	See pages 180–186.
E, 16, 1 mile southeast of Punta de la Sierra Loc. 245 F. S. No. 316A	Composite dike, 20 feet thick	*Porphyritic quartz trachyte.* Dove-gray rock with trachytic groundmass of microlitic alkali feldspar, green sodic pyroxene, magnetite, and about 3% interstitial quartz; grain size is minute up to 0.2 mm. Phenocrysts and glomerocrysts are microperthitic, feldspar (albitized?) up to 3×4 mm, and gray partly altered augite up to 0.5×1 mm, some of which occurs as inclusions in feldspar. Magnetite is anhedral to euhedral and also occurs as inclusions in augite.
E, 16, 3 miles south of Dominguez Mountain Loc. 246 F. S. No. 804	Discordant(?) dike poorly exposed in alluvium, 0.2 mile in diameter	*Porphyritic trachyte.* Brownish-red porphyritic rock with three sizes of constituents: (1) dense groundmass of alkali feldspar and abundant altered pyroxene(?), 0.01 to 0.03 mm; (2) laths of alkali feldspar with Carlsbad twins average 0.02 mm; (3) untwinned phenocrysts and glomerocrysts of anhedral orthoclase up to 4×6 mm, one with plagioclase core, euhedral to subhedral green augite up to 0.8 mm, and altered fayalitic olivine (2V large, negative) up to 0.4 mm. Groundmass is flow banded.

G, 17, Elephant Tusk Loc. 247 F. S. No. 215	Plug, 0.3 mile in diameter	*Riebeckite quartz trachyte.* Light gray weathered trachytic groundmass composed of alkali feldspar microlites and sponges and wisps of altered riebeckite(?) with rare altered feldspar phenocrysts to 1 × 2 mm.
G-H, 19–20, southwest of Glenn Springs Loc. 248 F. S. No. 12	Dike, 2 to 10 feet thick, exposed intermittently for 2 miles	*Porphyritic trachyte(?).* Too decomposed for description.
F, 19, west flank of Mariscal Mountain Loc. 249	Bands and lenses to 8 inches thick in olivine gabbro sill, Loc. 354	*Alkalic syenite.* An unusually striking light gray hypautomorphic-granular seriate (minute to about 2 mm) aggregate of feldspar, pyroxene, amphibole, and brown secondary material which may have replaced analcite. Feldspar is mainly subhedral laths of turbid patchy microperthitic, some with Carlsbad twins and some with clear margins of sanidine-anorthoclase. There are limited discrete laths of sanidine-anorthoclase and oligoclase (An_{12}). Pyroxene includes gray clinopyroxene zoned to emerald green aegirine ($Z\Lambda c = 4°$) and intergrown with arfvedsonite ($2V = 30° \pm$; $Z\Lambda c = 30°$) pleochroic in brown, green, and blue. Discrete grains of aegirine and arfvedsonite also are present. Many ore grains are enclosed in mafic minerals; there are traces of apatite and zircon.

SYENOGABBRO-SYENODIORITE AND FINE-GRAINED EQUIVALENTS

(Loc. Nos. 250–266)

Q, 13, east flank of Christmas Mountains (See also R, 10, on inset map) Loc. 250 F. S. Nos. 84, 926D	Dike, 50 feet thick, exposed 0.7 mile	*Porphyritic trachyandesite.* Black, weathers gray, seriate porphyritic rock with largest phenocrysts slender laths of andesine (An_{44}) up to 3 mm. Other phenocrysts are partly resorbed brown hornblende ($Z \Lambda c = 10°$), minute ore grains, and rare gray augite ($Z \Lambda c = 43°$). Groundmass is mainly plagioclase laths armored with alkali feldspar and interstitial brown faintly polarizing secondary material along with minute prismatic grains of light green clinopyroxene, ore grains, and a trace of apatite.
O, 14, 4 miles northwest of Burro Mesa Loc. 251 F. S. No. 484	Concordant laccolith 50 to 60 feet thick, exposed over area 0.5 × 1 mile; syenite bands a few inches thick and sporadic roof pendants	*Syenodiorite.* Weathered fine-grained aggregate of andesine (An_{48}), alkali feldspar, completely altered mafic minerals, ore grains, and minor biotite and apatite.
P, 17, southeast flank of Paint Gap Hills Loc. 252 F. S. No. 501A	Sill, 30 feet thick, exposed irregularly	*Syenodiorite.* Fine- to medium-grained, hypautomorphic-granular rock with mafic minerals completely altered and feldspar altered. Andesine(?) and alkali feldspar are about equal.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
O, 17, 4 miles southwest of Grapevine Hills Loc. 253 F. S. No. 50A	Sill, 30 feet thick, exposed 1 mile	*Trachyandesite porphyry.* Dark green to black rock with dense groundmass of altered alkali feldspar, altered mafic minerals, ore grains, and apatite, with phenocrysts of andesine (An_{48}) up to 5 × 5 mm. Quartz is apparently primary in narrow bands in groundmass.
P, 22, west flank of McKinney Hills Loc. 254 F. S. No. 410	Discordant lens, 10 to 40 feet thick, outcrop area 0.1 × 0.2 mile	*Syenogabbro.* Weathered xenomorphic-granular medium-grained (average 2 to 3 mm) aggregate of laboradorite (An_{63}), alkali feldspar, purple augite ($Z \wedge c = 43°$; $2V = 45° \pm$) and magnetite-ilmenite with minor finer interstitial weathered alkali feldspar, plagioclase, biotite, and apatite. Secondary minerals include calcite, chlorite, pyrite, and leucoxene.
H-K, 1–4, top of Mesa de Anguila Loc. 255 F. S. Nos. 149, 150	Sill, 100 to 200 feet thick, exposed around bases of hills of Boquillas above general level of mesa	*Olivine syenogabbro porphyry.* Dark gray to black rock with fine-grained matrix of plagioclase, alkali feldspar, augite, olivine, ore minerals, and apatite in which are phenocrysts and glomerocrysts of plagioclase and augite and olivine with seriate range nearly to groundmass. Plagioclase phenocrysts and glomerocrysts up to 8 mm show oscillatory zoning (An_{58-79}); some have minor rims of alkali feldspar and many contain inclusions of mafic minerals. Augite is grayish purple ($Z \wedge c = 45°$; $2V = 45° \pm$) up to 1.5 × 2 mm with a few euhedral crystals; some grains are twinned and some have exsolution lamellae. Olivine is anhedral to euhedral (negative, $2V = 85° \pm$; $\nu - \alpha = 0.037$) up to 1.5 mm in length. Ore grains are up to 0.6 mm.
J, 11, 0.5 mile northwest of Bee Mountain Loc. 256 F. S. Nos. 615, 140	Sill, 20 to 25 feet thick, exposed 200 yards, dipping 25° to west	*Porphyritic syenogabbro.* Dark greenish very fine-grained rock with labradorite phenocrysts to 3 × 4 mm. Groundmass is a subtrachytic aggregate of alkali feldspar laths with weathered plagioclase cores, weathered purple titanaugite, and ore grains with average grain size about 0.2 mm.
L, 19, north flank of Hayes Ridge Loc. 257 F. S. No. 476	Dike, 40 feet thick, exposed 0.2 mile	*Porphyritic syenodiorite.* Very fine-grained groundmass contains andesine (An_{46}) phenocrysts up to 3 × 8 mm. Groundmass is turbid alkali feldspar and plagioclase, grayish-violet augite, ore grains, apatite, and abundant secondary products.
L, 19, east flank of Chisos Mountains Loc. 258 F. S. Nos. 538, 737B	Sill, 30 feet thick, exposed 1.5 miles	*Syenogabbro.* Fine-grained intergranular to subophitic aggregate of subparallel labradorite (An_{57}) laths averaging length 0.9 mm, interstitial turbid alkali feldspar, deep purple augite, ore grains, prominent needles of apatite, and chloritic secondary products. Toward the south end of the exposure the rock is grotesquely porphyritic with groups and clots of thin tabular feldspar phenocrysts to 10 × 10 mm.

L, 19, east flank of Chisos Mountains Loc. 259 F. S. Nos. 539, 737A	Sill, 20 to 60 feet thick, exposed 1.5 miles	*Porphyritic syenodiorite.* Fine-grained groundmass of andesine laths, interstitial turbid alkali feldspar, clinopyroxene grains and crystals, ore minerals, and apatite needles with rare andesine (An_{48}) phenocrysts and glomerocrysts to 5 × 5 mm and gray diopsidic(?) pyroxene ($2V = 60° \pm$; $Z \wedge c = 46°$) to 2 × 2 mm.
G, 8, 2 miles northwest of Castolon Loc. 260 F. S. Nos. 6A, 388	Sill or thin laccolith, 50 feet thick, exposed in irregular curve 0.1 × 0.7 mile; contains bands of light gray syenite up to 5 inches thick	*Olivine syenogabbro.* Gray medium-grained subophitic rock with irregular laths of labradorite (An_{59}), sanidine-anorthoclase ($2V = 40° \pm$) mantling labradorite and interstitial, partly serpentinized olivine (negative, $2V = 85° \pm$), opaque, grayish-purple augite, biotite, brown hornblende, and apatite. Feldspar 69%, olivine and alteration products 15%, opaque minerals 7%, augite 6%, apatite 2%, biotite 1%, hornblende tr.
F, 12, 2 miles southwest of Mule Ear Peak Loc. 261 F. S. No. 569	Dike, 20 feet thick, exposed 1.8 miles	*Porphyritic olivine trachybasalt.* Dark greenish-gray to black rock with a dense groundmass (average 0.1 mm) and labradorite phenocrysts to 10 × 10 mm. Groundmass includes anhedral to subhedral plagioclase and alkali feldspar, rod-shaped skeletal crystals of augite studded with minute grains of ore minerals, apatite needles and grains, and about 25% green secondary material. A few microphenocrysts of ore grains and secondary material probably after olivine are present.
D, 13, near Rio Grande Loc. 262 F. S. No. 491	Curved, discordant mass, 75 to 100 feet thick, standing as wall 75 feet high	*Trachyandesite porphyry.* Dark brownish-gray rock with groundmass (0.1 mm) containing abundant labradorite (An_{52}) phenocrysts up to 3 × 5 mm and microphenocrysts of gray augite, red iddingsite, and ore grains. Groundmass is composed about equally of alkali feldspar and oligoclase with many laths of latter mantled with alkali feldspar.
F, 14, 2.5 miles northwest of Punta de la Sierra Loc. 263 F. S. No. 626	Dike, 15 feet thick, cuts basal lava	*Porphyritic syenodiorite.* Dark green rock with hypautomorphic-granular seriate groundmass minute to about 0.1 mm of alkali feldspar, oligoclase(?), rods of green and purple clinopyroxene, grains of iron ore, and needles of apatite with rare phenocrysts of andesine (An_{45}) up to 4 × 5 mm and smaller masses of serpentine after olivine.
F-G, 15–16, Dominguez Mountain and dike swarm extending southwest into D, 12 (see pp. 257–265; 269–270) Loc. 264	Dike swarm	See pages 180–186.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
E, 22, 4 miles east of Mariscal Mountain Loc. 265 F. S. No. 423	Sill, 30 feet thick, divided into sheets, in places with shale intercalations	*Syenodiorite.* Fine-grained aggregate of weathered andesine(?), alkali feldspar, purple augite, ore grains, and secondary products.
E, 22, 4.6 miles east of Mariscal Mountain Loc. 266 F. S. No. 417	Discordant, dikelike, 40 to 50 feet thick, possibly related to Loc. 265	*Syenodiorite.* Fine-grained aggregate of weathered andesine(?), alkali feldspar, purple augite, ore grains, and secondary products.
	GABBRO-BASALT (Loc. Nos. 267–361)	
R, 2, 0.5 mile southeast of Persimmon Gap Loc. 267 F. S. No. 751	Sill(?), 10 feet thick, exposed 0.1 mile	*Microgabbro.* Weathered greenish-brown, fine-grained rock. Partly altered plagioclase is labradorite (An_{53}).
Q, 3, near Dog Canyon Loc. 268 F. S. No. 763A	Two dikes, 2 and 10 feet thick, exposed 0.1 mile	*Basalt.* Completely weathered rock replaced by secondary minerals.
Q, 3, southeast of Dog Canyon Loc. 269 F. S. No. 766	Dike, 5 feet thick, exposed 0.1 mile	*Basalt.* Completely weathered rock replaced by secondary minerals.
Q, 3, southeast of Dog Canyon Loc. 270 F. S. No. 765	Tabular, discordant, 20 feet thick, exposed 0.1 mile	*Gabbro.* Weathered. Not studied in detail.
Q, 13, east flank of Christmas Mountains (see R, 10, on inset map) Loc. 271 F. S. No. 926C	Dike, 10 to 15 feet thick, exposed 0.2 mile	*Gabbro.* Weathered gray medium-grained aggregate of labradorite (An_{62}) with minor gray to purple augite and ore grains. There are abundant fibrous zeolites and other secondary products, some of which possibly represent original biotites.

R, 13, near northwest corner of map (see S, 11–12, on inset map) Loc. 272 F. S. Nos. 81AB, 715	Two dikes, one 10 feet thick, one 4 feet thick; longer one exposed 1 mile	*Basalt.* Greenish weathered rock; plagioclase is An_{57}.
Q, 13, 1.5 miles east of Christmas Mountains (see Q, 11, on inset map) Loc. 273 F. S. No. 914C	Sill, 5 feet thick, exposed 200 yards	*Basalt.* Weathered rock with sparse plagioclase phenocrysts (An_{60}).
Q, 13, east of Christmas Mountains (see Q, 11, on inset map) Loc. 274 F. S. No. 914E	Tabular, discordant, 3 to 6 feet thick, exposed 0.2 mile	*Basalt.* Weathered.
N-O, 13, flanking north end of Burro Mesa Loc. 275 F. S. Nos. 912E, 458A	Irregular dikelike, up to 50 feet thick, interrupted	*Basalt.* Weathered; plagioclase An_{48-50}.
P, 13, northwest flank of Slickrock Mountain Loc. 276 F. S. No. 943	Sill, 10 feet thick, exposed 0.2 mile	*Basalt.* Not studied in detail.
R, 13, 1 mile northeast of Christmas Mountains Loc. 277 F. S. No. 83	Dike, 10 feet thick, exposed 0.2 mile	*Basalt.* Weathered. Not studied in detail.
R, 14, near northwest corner of map Loc. 278 F. S. No. 86	Dike, 10 feet thick, exposed 0.2 mile. About 30 feet from termination of two long dikes.	*Olivine basalt porphyry.* Black seriate porphyritic rock with a grain size range of about 0.008 for ore grains to 5 mm for plagioclase laths. The largest crystals are labradorite (An_{53}), some with alkali feldspar rims, which are lath-shaped up to 5 mm in length; olivine, a few euhedral, are up to 1.5×2 mm; ore grains are up to 0.6 mm, and grayish-violet augite is up to 1 mm. The smaller grains include these minerals along with interstitial alkali feldspar. A small number of brown hornblende(?) grains and apatite are present.
Q, 13–14, east of Christmas Mountains Loc. 279 F. S. No. 73	Dike, 10 to 15 feet thick, exposed 2 miles. At one place a sill offshoot exposed 0.4 mile	*Porphyritic basalt.* Dark greenish-gray groundmass of closely packed plagioclase laths average length about 0.1 mm, ore grains and brown turbid secondary interstitial material; abundant lath-shaped phenocrysts of labradorite (An_{57}) are up to 5 mm long and a few phenocrysts of weathered augite are up to 0.7 mm. There is a trace of apatite.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
O, 14, 1 mile west of Croton Peak Loc. 280 F. S. No. 189	Dike, 4 feet thick, cutting small felsite mass	*Basalt.* Grayish-green weathered rock; only plagioclase (An_{59}) phenocrysts (3 mm long) are determinable.
R, 19, 2 miles north of Grapevine Hills Loc. 281 F. S. No. 945	Dike, about 10 feet thick, exposed 0.5 mile (photogeology)	*Basalt.* Not studied in detail.
R, 19, 1.5 miles northwest of Grapevine Hills Loc. 282 F. S. No. 443	Two dikes, about 5 feet thick, exposed 0.2 mile	*Microgabbro.* Greenish-gray weathered rock.
Q, 19, 1 mile northwest of Grapevine Hills Loc. 283 F. S. No. 442	Sill, 5 feet thick, exposed 0.5 mile in canyon	*Microgabbro.* Greenish-gray weathered rock.
Q, 19, 0.5 mile northwest of Grapevine Hills Loc. 284 F. S. No. 449	Dike, 12 feet thick, exposed 0.2 mile	*Basalt.* Not studied in detail.
T, 21, 4.5 miles north of Tornillo Creek Loc. 285 F. S. No. 132	Dike, 2 feet thick, exposed 0.1 mile	*Basalt.* Weathered. Not studied in detail.
P, 21, 3 miles west of McKinney Hills Loc. 286 F. S. No. 461G	Sill, 12 feet thick, exposed 0.1 mile	*Porphyritic olivine microgabbro.* Black weathered rock consisting of a fine-grained groundmass in which plagioclase laths reach 0.9 mm in length, purple augite subophitic to plagioclase ($2V = 50° \pm$) 0.6 mm, iddingsite(?), and green secondary material from olivine, minor interstitial alkali feldspar, ore grains, and needles of apatite. Labradorite (An_{58}) phenocrysts are up to 3×6 mm with inclusions of augite and ore grains.

P, 21, 2.5 miles west of McKinney Hills Loc. 287 F. S. No. 461R	Dike, 16 feet thick, exposed 0.1 mile	*Porphyritic olivine microgabbro.* Similar to Loc. 286 except olivine is rare.
T, 22, 4 miles north of Tornillo Creek Loc. 288 F. S. No. 789	Dike, 5 feet thick, exposed 0.1 mile	*Basalt.* Completely weathered and replaced by secondary minerals.
Q, 22, 1 mile northwest of northwest edge of McKinney Hills Loc. 289 F. S. Nos. 373AB, 459	Four small masses, three forming conical hills 30 feet high and 50 to 75 yards in diameter; contacts concealed, probably plugs	*Olivine basalt porphyry.* Porphyritic black rock with phenocrysts comprising about 50%. Groundmass is hypautomorphic-granular. Average grain size 0.1 mm; contains labradorite, augite, olivine, ore grains, and apatite, along with a little interstitial alkali feldspar partly altered to turbid material. All phenocrysts are anhedral to euhedral and include labradorite (An_{63}) up to 6 × 10 mm with inclusions of augite, olivine, and ore grains; grayish-purple augite ($Z \wedge c = 49°$; $2V = 45° \pm$) up to 2.5 × 2.5 mm and olivine up to 1.5 × 1.5 mm are partly serpentinized. A few ore grains are of phenocryst size.
Q, 22, northwest flank of McKinney Hills Loc. 290 F. S. No. 374	Dike, 3 feet thick, exposed 0.3 mile	*Basalt.* Weathered. Not studied in detail.
O-Q, 22–23, between Tornillo Creek and McKinney Hills Loc. 291 F. S. Nos. 551, 906, 907, 908, 909, 891, 893, 894, 895, 504ABC	Twenty-odd dikes and sills, 1.5 to 6 feet thick, mainly exposed about 0.1 mile	*Basalt.* Basaltic, trachytic, and rhyolitic masses, all weathered; only the general nature is determinable.
K, 1, northwest end of Mesa de Anguila Loc. 292 F. S. No. 148	Lens-shaped sill, maximum thickness exposed 20 feet	*Olivine basalt.* Black, seriate porphyritic rock, grain size 0.005 to 1.5 mm, with rare much larger glomerocrysts of augite (6 × 6 mm) and anhedral plagioclase 3 mm. Plagioclase is labradorite (An_{52}) zoned, some with alkali feldspar rims. Olivine is anhedral to euhedral up to 1.5 mm long (optically (−), $nZ = 1.743$, $nZ + nX = 0.04$). Augite is brownish anhedral ($Z \wedge c = 48°$; $nZ = 1.728$). A very little biotite, alkali feldspar, and apatite occur among the smaller grains. Feldspar, 33%; larger augite grains, 10%; larger olivine grains, 16%; ore grains, 17%; groundmass olivine and augite, 25%.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
K, 3, north flank of Mesa de Anguila Loc. 293 F. S. No. 712	Lens, 125 feet maximum thickness, exposed 0.7 × 0.4 mile	*Olivine gabbro.* Dark gray medium-grained rock with a few feldspar crystals up to 5 mm and about 25% interstitial minerals with average grain size 0.2 mm. Larger minerals are labradorite, zoned (An_{54-64}) with inclusions of augite, ore grains, and olivine; augite grayish-violet ($Z \wedge c = 45°$; $2V = 40° \pm$) is subophitic to plagioclase—some crystals are euhedral and twinned to 2.5 mm; olivine, partly serpentinized, is up to 1.6 mm, some crystals euhedral; ore grains are partly derived from olivine. Interstitial minerals are plagioclase, alkali feldspar (anorthoclase?, $2V = 40° \pm$), augite, ore grains, apatite, and alteration products.
J-K, 5–6, west to southeast of Sierra Aguja Loc. 294 F. S. Nos. 1, 724, 851, 883, 846, 713AB	Tabular mass, 15 to 200 feet thick; mainly concordant but discordant and dikelike in places, exposed irregularly in an area 2 × 4 miles	*Porphyritic olivine basalt.* Varies in texture from types with a dense groundmass with average grain size 0.03 mm and phenocrysts up to 1.6 × 4 mm to a hypautomorphic-granular groundmass average grain size 0.1 mm and phenocrysts 3 × 3 mm. Phenocrysts in some specimens include labradorite An_{60}, zoned to An_{50}, some with alkali feldspar and partly ophitic rims, grayish-violet augite ($2V = 45° \pm$) up to 2 × 2 mm; olivine, some euhedral up to 2 × 2 mm, and ore minerals up to 0.6 mm. Groundmass includes the same minerals with in addition interstitial alkali feldspar, a trace of biotite, and apatite. In one specimen plagioclase phenocrysts, 18%; olivine phenocrysts, 8%; ore minerals, 21%; groundmass (plagioclase, augite, alkali feldspar, olivine), 53%. At K, 5, bands and lenses up to 18 inches thick of syenite are present.
J-K, 5–6, west and south flanks of Sierra Aguja Loc. 295 F. S. No. 942	Four or more weathered, poorly exposed dikes; weathered outcrops extend a few hundred feet	*Basalt.* Weathered. Not studied in detail.
J, 6, south end of Sierra Aguja Loc. 296 F. S. No. 848	Dike, variable thickness to 20 feet, exposed 1 mile	*Basalt.* Weathered. Not studied in detail.
J-K, 6, 2 miles east of Sierra Aguja Loc. 297 F. S. Nos. 849, 884	Sill, slightly discordant in places, 25 to 40 feet thick, exposed 1.3 miles	*Diabasic olivine basalt.* Varies from a fine-grained ophitic aggregate of augite, labradorite laths and ore grains with a few larger crystals of labradorite, augite, and altered olivine to types with minor groundmass and abundant labradorite crystals to 3 × 6 mm, augite 2 × 2 mm, and altered olivine to 1 × 1 mm. Labradorite is An_{66} zoned to andesine, augite, purplish ($Z \wedge c = 48°$; $2V = 55° \pm$), shows twinning and/or exsolution lamellae. Former presence of olivine is inferred from secondary minerals.

K, 9, east flank of Rattlesnake Mountain Loc. 298 F. S. No. 723	Dike, 3 feet thick, exposed 100 yards	*Basalt.* Decomposed. Not studied in detail.
L-M, 10, northwest of Tule Mountain Loc. 299 F. S. No. 754CDE	Three small discordant dikelike or pluglike masses	*Olivine basalt.* Dark green rock with dense weathered groundmass and phenocrysts and microphenocrysts of labradorite (An_{58}).
N, 10, southeast flank of Maverick Mountain Loc. 300 F. S. No. 755	Tabular, 20 feet thick, discordant at low angle	*Basalt.* Brown; too decomposed for study.
M, 11, 2 miles northeast of Tule Mountain Loc. 301 F. S. No. 579	Dike, 5 feet thick, exposed 0.4 mile	*Basalt.* Too altered for study.
N, 13, east flank of Burro Mesa Loc. 302 F. S. No. 594	Dike, 10 feet thick, exposed 0.1 mile	*Basalt.* Brownish-green rock; too decomposed for study.
K, 14, 2 miles southwest of Ward Mountain Loc. 303 F. S. No. 690A	Dike, 10 feet thick, exposed 0.2 mile	*Basalt.* Not studied in detail.
K, 14, 1.5 miles southwest of Ward Mountain Loc. 304 F. S. No. 581B	Dike, 10 feet thick, exposed 0.2 mile	*Basalt.* Too decomposed for study.
K, 14, 1 mile southwest of Ward Mountain Loc. 305 F. S. No. 928	Dike, 2 feet thick	*Basalt.* Not studied in detail.
N, 15, 3 miles northwest of Pulliam Peak Loc. 306 F. S. No. 670F	Dike, 3 feet thick, exposed 0.2 mile	*Basalt.* Green, decomposed.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
N, 16, 1.3 miles northwest of Pulliam Peak Loc. 307 F. S. No. 670F	Dike, 4 to 10 feet thick, exposed 0.2 mile	*Basalt.* Weathered. Not studied in detail.
L, 16, near east flank of Ward Mountain on trail to Window Loc. 308 F. S. No. 946	Dike, about 5 feet thick, exposed 0.1 mile	*Basalt.* Not studied in detail.
L, 17, at north foot of Casa Grande Loc. 309 F. S. Nos. 192C, 874A, A-1	Dike of variable thickness, maximum thickness 40 feet, exposed 0.5 mile, cuts "Chinese Wall"	*Porphyritic basalt.* Reddish-brown porphyritic rock with plagioclase (An_{56}) phenocrysts up to 6 × 6 mm. Groundmass is weathered with plagioclase laths and ore grains the only unaltered material.
L, 17, 0.8 mile northeast of Casa Grande on trail to Lost Mine Peak Loc. 310 F. S. No. 874B	Dike, variable, thickness to 40 feet	*Porphyritic basalt.* Varies in texture. Dark green to black rock with weathered dense groundmass and numerous phenocrysts of labradorite (An_{55}) up to 3 mm in length.
N, 18, 0.8 mile north of Panther Peak Loc. 311 F. S. No. 578	Dike, 5 feet thick, exposed 0.1 mile	*Basalt.* Weathered; feldspar is not determinable, purple augite is ophitic to feldspar.
M, 19, 0.7 mile northeast of Pummel Peak Loc. 312 F. S. No. 932	Sill, 35 feet thick, exposed 0.2 mile	*Basalt.* Not studied in detail.
M, 19, 0.5 mile northeast of Pummel Peak Loc. 313 F. S. No. 509U	Sill, 10 feet thick, exposed 0.1 mile	*Porphyritic basalt.* Dark green weathered rock with plagioclase phenocrysts to 7 × 7 mm in a weathered groundmass originally composed of plagioclase laths and mafic minerals.

M, 19, 0.4 mile northeast of Pummel Peak Loc. 314 F. S. No. 509Q	Sill, 20 feet thick, exposed 0.1 mile	*Diabase.* Dark greenish-gray to black subophitic rock with grain size on the order of 0.4 mm with rare plagioclase microphenocrysts. Plagioclase laths are altered; purple augite is fresh. Abundant green secondary material occurs interstitially and as discrete grains, possibly after olivine. Ore grains are prominent; there is a trace of apatite.
L, 19, 1.5 miles southeast of Pummel Peak Loc. 315 F. S. No. 948	Dike, about 5 feet thick, exposed 0.2 mile (photogeology)	*Basalt.* Not studied in detail.
L, 19, 1.3 miles south of Pummel Peak Loc. 316 F. S. No. 686B	Plug, 100 feet in diameter	*Basalt.* Dense black microcrystalline aggregate of ore grains, clinopyroxene, and plagioclase.
G-H, 7, southeast of Santa Elena Canyon about 1 mile from Rio Grande Loc. 317 F. S. No. 575-O	Sill, maximum, 40 feet	*Porphyritic olivine basalt.* Similar to Loc. 319.
G, 7, near Rio Grande Loc. 318 F. S. No. 750B	Dike, 6 feet thick, exposed 0.2 mile	*Porphyritic basalt.* Weathered rock with dense groundmass and rare relict phenocrysts of labradorite (AN_{50}).
H-J, 7–8, northwest of Castolon Loc. 319 F. S. Nos. 4, 383, 385	Several separated masses probably originally parts of same mass, mainly tabular, concordant, 25 60 feet thick; locally discordant	*Porphyritic olivine basalt.* Groundmass in different samples varies from dense felty mass with average grain size about 0.05 mm to hypautomorphic-granular aggregate with grain size approaching microgabbro. Groundmass materials are grayish-lavender augite, laths of plagioclase (An_{56}), olivine, interstitial alkali feldspar, ore grains, apatite, and rare biotite from reaction. Phenocrysts are plagioclase (An_{62}) with inclusions of mafic minerals up to 3×6 mm, olivine up to 2×3 mm, some euhedral, and augite partly ophitic to plagioclase ($Z\Lambda c = 39°$; $2V = 45° \pm$) up to 2×3 mm. In coarser specimens, some ore grains are microphenocrysts to 0.9×0.9 mm. Amount of alkali feldspar varies and some rocks are close to syenogabbro.
H, 8, 4 miles south of Rattlesnake Mountain Loc. 320 F. S. No. 757ABCDE	Group of weathered dikes 10 to 40 feet thick	*Diabase.* One sample is a weathered ophitic aggregate of purplish augite, labradorite laths about 0.2 mm, ore grains, and apatite with a few labradorite (An_{62}) phenocrysts up to 3 mm.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
G-H, 8, along Alamo Creek Loc. 321 F. S. Nos. 7, 384, 387, 749EFKS	Discordant, dikelike, 10 to 50 feet thick, with curved interrupted exposure 3.5 miles in length; probably related to mass Loc. 322	*Olivine basalt.* Partly porphyritic. Similar to rocks in Locs. 322 and 323. One sample has plagioclase, 56%; augite, 23%; olivine, 11%; ore minerals, 9%; biotite and apatite, tr. Plagioclase ranges from An_{53} to A_{60}.
H, 8, on Alamo Creek near Rio Grande Loc. 322 F. S. Nos. 386, 749G	Dike, 10 feet thick, cut by mass Loc. 321	*Olivine basalt.* Black, dense rock varying from microcrystalline to trachytic with average grain size 0.05 mm and with a very few microphenocrysts about 0.5 mm. Augite, ore grains, and olivine constitute about 45% of the rocks, labradorite (An_{62}) constitutes about 55%. There is a trace of interstitial alkali feldspar and biotite.
G, 9, northwest of Castolon F. S. No. 749H	Tabular, concordant, 5 feet thick, exposed 0.1 mile, possibly related to mass Loc. 260	*Basalt.* Weathered. Not studied in detail.
H, 9, 2 miles south of Peña Mountain Loc. 324 F. S. No. 749C	Dike, 10 to 20 feet thick, exposed 0.2 mile	*Olivine diabase.* Dark gray to black rock, ophitic, with about 55% labradorite (An_{60}) laths average length 0.2 mm, 25% deep reddish-purple augite (color so deep it masks interference colors), 15% ore grains, and 10% partly serpentinized olivine along with considerable secondary interstitial calcite.
H, 9, 1.5 miles south of Peña Mountain Loc. 325 F. S. No. 749B	Dike, 10 to 20 feet thick, exposed 0.6 mile; cuts mass Loc. 321	*Basalt.* Black dense microcrystalline aggregate of clinopyroxene, ore grains, plagioclase laths, and interstitial alkali feldspar.
J, 9, 1 mile southeast of Peña Mountain Loc. 326 F. S. No. 749A	Tabular, 20 to 30 feet thick, exposed 0.5 mile	*Olivine diabase.* Black to greenish, fine-grained rock with a few phenocrysts of labradorite (An_{62}) up to 4×7 mm. Purplish augite ($Z\Lambda c = 42°$; $2V = 50° \pm$) occurs in anhedral grains to 2 mm ophitic to labradorite laths which average 0.2 mm. There are rare euhedral pseudomorphs after olivine up to 2×2 mm; similar finer material may be from olivine. Ore grains are abundant; interstitial alkali feldspar occurs in minor quantities: there is a trace of apatite.
J, 9, 0.4 mile east of Peña Mountain Loc. 327 F. S. No. 585	Discordant, pluglike, 0.1×0.2 mile	*Porphyritic olivine basalt.* Black porphyritic rock with phenocrysts of zoned labradorite (An_{63}) to 1×3 mm, rare augite to 1.6 mm, and completely altered olivine to 1×2 mm. Groundmass is seriate with labradorite laths to 0.3 mm, augite ($Z\Lambda c = 47°$; $2V = 55° \pm$) partly subhedral ophitic to labradorite up to 0.4 mm, olivine partly serpentinized to 0.1 mm, ore grains to 0.3 mm, interstitial alkali feldspar and apatite.

J, 13, 4 miles west of Sierra Quemada Loc. 328 F. S. No. 939	Irregular dike, on bank of Blue Creek, exposed 0.2 mile	*Basalt.* Not studied in detail.
J, 16, north of Sierra Quemada Loc. 329 F. S. No. 137	Sill, 40 feet thick, exposed in curved outcrop 2.7 miles long	*Porphyritic basalt.* Trachytic groundmass with laths of plagioclase, grayish-purple augite, ore grains, and greenish, turbid, interstitial material with average grain size about 0.1 mm and phenocrysts of labradorite (An_{70}) partly replaced by zeolite minerals.
F-G, 15–16, Dominguez Mountain and dike swarm extending southwest into D, 12 (see pp. 257–265; 269–270) Loc. 330	Dominguez Mountain, a composite intrusion with dike swarm	See pages 180–186.
J-H, 17, circling Tortuga Mountain Loc. 331 F. S. Nos. 163, 302, 354	Sill, 40 to 100 feet thick, crops out in a circle 1 mile in diameter on periphery of dome	*Gabbro.* Dark gray medium-grained rock with largest feldspar crystals 5 × 8 mm and augite to 4 mm. Texture is seriate and partly ophitic. Labradorite is zoned An_{50-60} and albitized with trace of replacement by analcite. Augite is faint gray to colorless ($Z\Lambda c = 45°$; $2V = 55° \pm$) and replaced by deep red biotite ($2V = 18° \pm$) and magnetite, and subsequently by chlorite and pyrite through hydrothermal alteration.
H, 17, 1.3 miles northwest of Elephant Tusk Loc. 332 F. S. No. 935	Tabular, roughly concordant, 50 feet thick with roof remnants (photogeology)	*Gabbro.* Not sampled, probably related to Loc. 333.
H, 17, 1 mile southeast of Tortuga Mountain Loc. 333 F. S. No. 805	Laccolith, 150 feet thick, exposed 1 × 0.7 mile	*Gabbro.* Dark gray to black xenomorphic-granular seriate aggregate of labradorite (An_{58}), gray augite, brown secondary material, and ore grains minute to 0.9 mm with rare glomerocrysts of augite ($Z\Lambda c = 49°$; $2V = 40° \pm$) up to 5.5 mm. The brown secondary mineral may be derived from olivine. Rock is poor in ore grains and apatite in contrast to other gabbroic rocks of area; many of the plagioclase grains are shattered.
G-H, 17, 0.5 mile northwest of Elephant Tusk Loc. 334 F. S. No. 937	Tabular to laccolithic(?), 150 feet thick, with roof remnants (photogeology)	*Gabbro.* Not sampled, probably related to Loc. 333.
G, 18, 1 mile southeast of Elephant Tusk Loc. 335 F. S. No. 549	Dike, 15 feet thick, exposed intermittently 0.5 mile	*Basalt.* Decomposed. Not studied in detail.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
H, 18, 2.5 miles southeast of Tortuga Mountain in Fresno Creek Loc. 336 F. S. No. 548	Three sills about 12 feet thick, exposed in both canyon walls	*Basalt.* Weathered and largely replaced by calcite and chloritic material. Secondary quartz occurs in vesicles.
H, 18–19, 3 miles east of Tortuga Mountain Loc. 337 F. S. No. 933	Dikes, 4 to 10 feet thick, exposed for short distances in arroyos	*Basalt.* Not studied in detail.
G, 19, 2.5 miles northwest of Mariscal Mountain Loc. 338 F. S. Nos. 545, 546, 547	Three dikes, 5.5 and 10 feet, exposed 0.2 to 1 mile	*Basalt.* Dense to fine-grained weathered rock replaced largely by calcite. In one sample plagioclase is labradorite (An_{62}).
G, 19, 1 mile west of Talley Mountain Loc. 339 F. S. Nos. 23A, 529B, 827; 23B is analcite	Sill, 10 to 30 feet thick, exposed 1.5 miles	*Olivine microgabbro(?).* Green to brown badly altered rock (only original plagioclase and ore grains remain) consisting of an aggregate of subhedral laths of plagioclase (An_{53}) with average length 0.3 mm with a few slightly larger crystals, ore grains, apatite, and interstitial secondary material. Original texture was subophitic.
G, 19, 0.6 mile west of Talley Mountain Loc. 340 F. S. No. 915A	Dike, 30 feet thick, exposed 0.3 mile	*Microgabbro.* Xenomorphic-granular aggregate of purple augite, laths of labradorite, and ore grains with rare phenocrysts of labradorite (An_{56}) up to 2×3 mm.
G, 19, 0.5 mile west of Talley Mountain Loc. 341 F. S. No. 828	Dike, 1 to 15 feet thick, exposed 0.2 mile	*Basalt porphyry.* Dark green weathered rock with a dense groundmass largely replaced by calcite and other secondary minerals; phenocrysts and glomerocrysts of labradorite (An_{62}) are up to 5×5 mm.
G, 20, northwest flank of Talley Mountain Loc. 342 F. S. No. 803B	Two sills, 2 to 4 feet thick, exposed 0.2 mile	*Microgabbro.* Dark green weathered rock. All original constituents except plagioclase, ore grains, and apatite have been replaced by secondary minerals. Labradorite (An_{54}) laths and quadratic crystals are seriate from minute to 1 mm. Small grains of red iddingsite(?) may have been derived from olivine.

G, 20, 0.6 mile north of Talley Mountain Loc. 343 F. S. No. 803A	Two dikes, 1 to 3 feet thick, exposed 0.4 mile	*Basalt porphyry.* Dense weathered groundmass with original plagioclase laths up to 0.1 mm; unweathered phenocrysts and glomerocrysts of labradorite (An_{60}) are up to 5 × 7 mm.
G, 21, 0.5 mile south of Chilicotal Mountain Loc. 344 F. S. No. 522	Dike, 2 feet thick, exposed 0.1 mile	*Basalt porphyry.* Decomposed. Not studied in detail.
H, 21, south end of Chilicotal Mountain Loc. 345 F. S. Nos. 290, 358A, 359AB, 416	Tabular, sill-like mass up to 75 feet thick immediately beneath main rock of the mountain	*Microgabbro.* Dark gray to greenish altered rock; texture is seriate with grain size range from minute to 3 mm. Most specimens are altered and contain abundant calcite and zeolitic material. Plagioclase laths are relatively fresh labradorite (An_{57}) up to 3 mm; purple augite ($2V = 50° \pm$) up to 2.5 mm is ophitic to feldspar; biotite about 1% is derived from reaction. Ore grains are abundant. Interstitial alkali feldspar is completely altered.
H, 22, 1 mile east of south end of Chilicotal Mountain Loc. 346 F. S. No. 367	Six separated remnants of sill about 30 feet thick; probably original part of mass Loc. 345; contain stringers of syenite a few inches maximum thickness	*Microgabbro.* Generally similar to Loc. 345. May have contained olivine; there is a slight replacement of plagioclase by analcite; apatite is prominent.
H, 22, 2.3 miles east of south end of Chilicotal Mountain Loc. 347 F. S. No. 368	Dike, 6 to 10 feet thick, exposed 0.6 mile	*Olivine basalt.* Dark gray to dark green rock, average grain size about 0.1 mm with a few plagioclase laths up to 1.5 mm. Mafic minerals, originally subophitic, are completely replaced by chloritic material, and interstitial alkali feldspar is replaced by calcite. Plagioclase (An_{54}), ore grains (some probably from reaction), biotite, and apatite are the only unaltered minerals.
G, 23–24, G-H, 25, J, 25, southeastern part of area Loc. 348 F. S. Nos. 365, 366ABC, 369, 369A, 520, 521	Group of dikes 1 to 15 feet thick, exposed sporadically for 6 miles	*Basalt.* Decomposed and replaced by calcite and other secondary minerals.
E, 16, 1 mile east of Punta de la Sierra Loc. 349 F. S. No. 316B	Composite dike, 20 feet thick	*Basalt.* Dense trachytic aggregate of plagioclase laths, clinopyroxene and ore grains, average grain size 0.05 mm, with rare microphenocrysts of labradorite (An_{60}) up to 0.3 × 2 mm.
E, 16, 2 miles south of Dominguez Mountain Loc. 350 F. S. No. 929	Dike, 10 feet thick, exposed 0.1 mile	*Basalt.* Not studied in detail.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
D, 16, 4 miles south of Dominguez Mountain Loc. 351 F. S. No. 804	Dike, 10 feet thick, exposed 100 yards	*Basalt.* Decomposed. Not studied in detail.
C, 18, 4 miles north of Rio Grande Loc. 352 F. S. No. 495?, 494	Dike, 3 feet thick, exposed 0.1 mile	*Basalt.* Decomposed. Not studied in detail.
D, 19, 1 mile west of Mariscal Mountain Loc. 353 F. S. No. 420	Three exposures, probably all same mass, discordant, exposed for a few yards	*Olivine basalt.* Black dense aggregate of greenish-gray clinopyroxene microlites average about 0.03 mm, ore grains and glassy interstitial material with larger plagioclase laths (average 0.08) about 10% and serpentine pseudomorphs (about 0.1 mm, some euhedral) after olivine about 10%. Rare vugs are filled with analcite and calcite.
A-D, 20, D-F, 19, F, 20–21, west flank of Mariscal Mountain and northeast of the mountain Loc. 354 F. S. Nos. 14, 16, 17, 219, 497A, 517A, 532, 807	Tabular mass, 50 to 150 feet thick, exposed for 14 miles on west and northeast flanks of anticlinal structure. In places interrupted and in places separated into two bodies. Transgresses from near base of Terlingua to lower part of Aguja without losing tabular form. In places contains beds and lenses of alkalic syenite up to 8 inches thick	*Olivine gabbro.* More than 50% of the rock is plagioclase, augite, olivine (completely altered), and ore grains generally xenomorphic-granular, with a few subhedral crystals with a grain size 1 to 10 mm; remainder is plagioclase laths, augite grains, ore grains, alkali feldspar, biotite, and apatite of much smaller grain size. General aspect is equigranular medium grained. The plagioclase in various samples ranges from An_{58-70} with most about An_{65}. Augite is faintly purple ($Z\Lambda c = 47°$; $2V = 45° \pm$) and is partly ophitic to plagioclase. Ore grains contain inclusions of plagioclase and many are rimmed with biotite. Original presence of olivine is inferred from alteration products. Alkali feldspar (anorthoclase?) is in anhedral grains and in laths. Some specimens contain very small prismatic grains of green aegiritic pyroxene. All specimens are altered. Olivine is completely replaced, plagioclase is albitized and also replaced by zeolites, alkali feldspar is replaced by a fine aggregate probably of zeolite minerals. There is a trace of analcite in some specimens.
F, 19, north end of Mariscal Mountain Loc. 355 F. S. No. 499	Sill, 10 feet thick, exposed 0.3 mile	*Porphyritic basalt.* Greenish dense groundmass, largely replaced by calcite and chloritic material, with phenocrysts of labradorite (An_{66}) up to 4×4 mm.
E, 20, northeast flank of Mariscal Mountain Loc. 356 F. S. No. 419	Dike, 8 feet thick, exposed 0.2 mile	*Diabase.* Dark grayish-green weathered seriate aggregrate of labradorite (An_{55}) laths, purplish augite ophitic to labradorite, ore grains, and apatite. Nearly half of rock is composed of calcite and green secondary material, some possibly from olivine.

D, 21, east flank of Mariscal Mountain Loc. 357 F. S. No. 927	Dike, 10 feet thick, exposed 0.3 mile	*Basalt.* Not studied in detail.
E-F, 20–22, southeast of Talley Mountain Loc. 358 F. S. Nos. 527, 531, 833, 834, 835	Group of dikes, 4 to 20 feet thick, probably related to mass 354	*Porphyritic basalt.* Most samples are weathered. Freshest samples show groundmass about 0.1 mm with labradorite (An_{50}) laths, ore grains, and apatite as the only unaltered minerals. In most specimens there are abundant phenocrysts and glomerocrysts of labradorite (An_{66}) up to 6 × 10 mm.
F, 23, 1.4 miles from Rio Grande Loc. 359 F. S. No. 526AB	Tabular, 20 feet thick, small exposure	*Microgabbro.* Dark gray rock seriate from minute to about 1 mm. Largest elements are laths of labradorite (An_{56}). Rock is weathered with labradorite, abundant ore grains, trace biotite, and apatite as the only fresh minerals.
E, 23, 1.2 miles from Rio Grande Loc. 360 F. S. No. 525	Four dikes less than 1 foot thick, exposed 0.1 mile	*Basalt.* Not studied in detail.
E-F, 24, near Rio Grande Loc. 361 F. S. No. 414	Dike, 4 feet thick, exposed intermittently	*Basalt.* Greenish-gray rock with plagioclase laths and ore grains as the only unweathered minerals.
	MELABASALT (Locs. Nos. 362–365)	
P, 12, southeast of Christmas Mountains (see N, 7 on inset map) Loc. 362 F. S. No. 97	Irregular pluglike mass 0.1 mile in diameter	*Olivine melabasalt.* Dark green to black microporphyritic rock with microphenocrysts of olivine and augite to 1 mm in length in a groundmass of the same minerals, plagioclase laths, and ore grains. Augite is brownish gray zoned ($Z\wedge c = 48° - 50°$); olivine is colorless (positive 2V large); plagioclase labradorite (An_{62}) minute laths. Mode: augite, 44%; olivine, 19%; plagioclase, 18%; ores, 7%; groundmass, 12%; apatite, tr.
R, 14, near north edge of map, two small hills 0.2 mile and 0.1 × 0.4 mile separated by narrow band of sediment Loc. 363 F. S. No. 71AB	Possible remnants of uncovered sill about 50 feet thick	*Porphyritic olivine melabasalt.* Black rock with a dense groundmass in which are numerous euhedral to subhedral microphenocrysts of olivine up to 1 × 2 mm. The groundmass consists of brownish-gray augite ($Z\wedge c = 50°$) grains and prismatic crystals, labradorite laths, ore grains, and brownish turbid feldspathic interstitial material; the weathered part may be analcite. Mode: augite, 41%; olivine, 17%; plagioclase, 10%; ore, 7%; turbid groundmass, 25%. *Analyzed specimen.* Another section is essentially the same except it contains a few larger augite crystals and some of the interstitial material is fibrous, isotropic, and of low index. Mode: augite, 41%; olivine, 16%; plagioclase, 11%; ores, 5%; interstitial groundmass, 27%.

TABLE 13—(Continued)

PLATE II COORDINATES LOCALITY NUMBER FIELD SAMPLE NUMBER	TYPE OF INTRUSION	NAME AND DESCRIPTIVE REMARKS
N-O, 15, 3.5 miles west of Government Spring laccolith Loc. 364 F. S. Nos. 51, 840A	Lower of two sills about 8 feet thick forming hill	*Olivine melabasalt.* Dark gray to black hypautomorphic-granular aggregate of fresh colorless olivine, gray to brownish-violet zoned augite, ore grains and laths of labradorite; grain size is minute to 3 mm (attained only by rare olivine crystals). Mode: augite, 42%; olivine, 16%; plagioclase, 14%; ore grains, 9%; and turbid indeterminate groundmass, 19%. Another section has relatively abundant apatite and possibly analcite in groundmass. Olivine 2V large; augite zoned $Z \wedge c = 45° - 57°$, twinned. 2V about 55°.
O, 15, 3.5 miles west of Government Spring laccolith Loc. 365 F. S. No. 840B	Upper of two sills about 8 feet thick forming hill	*Porphyritic melabasalt.* Dark gray to black microporphyritic rock with euhedral to anhedral microphenocrysts of olivine up to 2×2.5 mm and microphenocrysts and glomerocrysts of gray to brown augite in a groundmass of the same minerals, grains of iron ore, laths of labradorite, and turbid interstitial feldspathic material with wisps of hornblende. Olivine (positive, 2V large; augite, moderate 2V). Analyzed specimen. See item no. 104, table 14, pages 263–265.

TABLE 14.—Chemical analyses, CIPW norms, and modes of igneous rocks, Big Bend region.

Item No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field No.		689F-2	234			882A	203		232D	285C	275	50B	240			162B
Lab. Ref. No.		796	56203			56205	R1103		R1340	56218	56201	56225	56211			R1339
CHEMICAL ANALYSES																
Analyst[1]	D	A	A	E	D	A	B	D	C	A	A	A	A	E	D	C
Specific gravity	....	2.62	2.67	....	....	2.65	....	....	....	2.64	2.64	2.63	2.63	....	....	....
SiO_2	76.71	76.47	76.42	76.30	76.23	76.19	75.90	75.53	75.39	75.33	75.26	75.26	75.00	74.85	74.72	74.64
Al_2O_3	12.15	11.57	10.24	11.53	12.11	9.87	11.69	12.26	12.56	10.37	10.88	13.33	12.71	12.83	14.12	11.54
Fe_2O_3	0.94	2.43	1.49	1.83	0.42	2.31	1.89	1.56	1.09	2.30	1.71	0.19	0.89	1.40	0.18	1.41
FeO	0.60	0.42	1.68	0.76		1.48	0.82	0.73	0.81	1.22	1.48	0.14	0.58	0.37		1.86
MgO	0.18	0.16	0.10	0.03	0.46	0.49	....	0.07	0.01	0.07	0.27	0.26	0.12	0.04	0.19	0.08
CaO	0.05	0.22	0.65	0.16	0.36	0.31	0.29	0.16	0.39	0.51	0.44	0.63	0.33	0.48	0.26	0.64
Na_2O	4.73	3.91	3.66	4.01	1.40	3.62	3.99	5.24	4.49	4.30	4.08	3.82	4.07	4.24	3.77	3.94
K_2O	3.88	4.63	4.50	4.70	4.93	4.76	4.64	4.05	4.61	4.55	4.70	4.82	5.10	5.12	4.57	4.48
H_2O+	0.31	....	....	0.34	1.47	....	0.13	....	0.22	....	....	....	....	0.30	0.95	0.39
H_2O-	0.11	0.17	0.46	0.19	1.80	0.42	0.09	0.13	0.09	0.18	0.22	0.37	0.29	0.24	0.33	0.29
TiO_2	0.09	0.25	0.23	0.16	....	0.25	0.14	0.10	0.12	0.22	0.22	0.14	0.15	0.15	0.12	0.17
ZrO_2	....	....	....	0.11	0.13	....	....	....	....	....	....	....	....	0.09	....	....
P_2O_5	0.02	0.01	0.02	....	0.01	0.03	....	0.01	0.01	0.02	0.03	0.01	0.01	....	....	....
MnO	....	0.03	0.05	tr	....	0.08	0.02	....	0.03	0.07	0.07	....	0.02	tr	0.07	0.07
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	tr	....	....	tr	....	....	....	....	....	....	....	....	....	tr	....	0.07
Ignition Loss	....	0.48	0.41	....	0.92	0.58	....	....	....	0.47	0.64	1.30	0.69	....	....	....
Total	99.77	100.76	99.91	100.14	100.24	100.39	99.60	99.84	99.82	99.61	100.00	100.27	99.96	99.82	99.58	99.58

[1] Analyst—
A. D. A. Schofield, Mineral Studies Laboratory, Bureau of Economic Geology, The University of Texas, Austin.
B. James Ken, GSA Laboratories, University of Minnesota, Minneapolis (Maxwell, Lonsdale, and Dickson, 1949, pp. 21–26).
C. Eileen H. Kane, GSA Laboratories, University of Minnesota (idem).
D. R. B. Ellestad, GSA Laboratories, University of Minnesota (Lonsdale, 1940, p. 1618, table 17).
E. W. F. Hillebrand (U. S. Geol. Survey Prof. Paper 99, p. 120, 1917).

TABLE 14—(Continued)

Item No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field No.		689F-2	234			882A	203		232D	285C	275	50B	240			162B
Lab. Ref. No.		796	56203			56205	R1103		R1340	56218	56201	56225	56211			R1339
NORMS[2]																
Q	34.68	35.52	37.92	34.92	47.90	36.72	34.80	30.06	30.72	33.78	32.88	33.24	30.72	30.12	34.50	32.46
or	22.80	27.24	26.69	27.28	28.91	27.80	27.24	23.91	27.24	26.69	27.80	38.36	30.02	30.02	27.24	26.69
ab	39.82	33.01	27.25	33.01	12.05	24.63	33.54	....	38.25	28.30	29.87	31.69	35.11	35.63	31.44	33.54
an	0.28	0.56	....	....	1.39	0.58	0.56	0.46	0.56	0.52	....	3.06	1.11	1.11	1.11	0.28
di	....	0.43	2.91	0.22	....	1.18	....	0.66	0.75	2.25	1.67	....	0.22	0.22	....	2.20
hy	0.66	0.26	1.06	....	1.13	2.45	....	....	....	0.66	1.72	0.60	0.20	....	0.40	1.02
ac	....	....	2.31	0.92	....	5.08	....	....	....	6.47	4.16	....	....	....	....	....
wo	....	....	....	0.23	....	0.40	0.35	....	0.23	....	....	....	....	0.46	....	....
ol	....	....	....	....	0.23	....	....	0.70	....	....	....	....	....	....	....	....
mt	1.16	0.70	0.46	2.09	....	0.70	2.09	....	1.62	1.19	0.46	0.23	1.39	0.70	0.41	2.09
hm	....	1.92	....	....	0.15	....	0.48	....	....	....	....	....	....	0.96	....	....
il	0.15	0.46	0.46	0.30	....	0.46	0.30	....	0.15	....	0.46	0.15	0.30	0.30	0.15	0.30
ap	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ru	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
calcite (cc)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0.20
pf or ns	....	....	....	....	....	....	....	....	....	0.12	....	....	....	....	....	....
th	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ne	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ti	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	3.98	....	....	....	....	....	....	0.77	....	....	2.55	....
MODES[2]																
Quartz	17.8	....	....	....	4.9(P)	..	5.5(P)	19.2	27.3	....	....	....	....	8.0	....	32.5
Qtz.-feld. gm.	....	....	....	....	82.1	....	79.5	....	....	....	....	....	....	....	....	....
Sodic orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	72.9	....	....	....	....	....	....	....	....
Alkali feldspar	76.6	....	....	....	13.0(P)	..	6.0(P)	....	67.6	....	....	....	....	92.0	....	51.1
Kind of alk. feld.	....	....	....	....	....	....	....	....	An_2	....	....	....	....	....	....	An_6
Plagioclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Kind of plagioclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Aegirine-augite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Aegirine	tr	....	....	....	....	....	....	tr	....	....	....	....	....	....	....	....
Riebeckite	5.6	....	....	....	....	....	7.9	7.9	4.7	....	....	....	....	....	....	15.0
Arfvedsonite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hornblende	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Olivine-serpentine	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Biotite	----	----	----	----	----	----	----	----	tr	----	----	----	----	----	----	1.0
Ores	----	----	----	----	----	----	0.3	----	0.4	----	----	----	----	----	----	0.3
Zircon	----	----	----	----	----	----	tr	----	----	----	----	----	----	----	----	0.1
Fluorite	----	----	----	----	----	----	tr	----	----	----	----	----	----	----	----	----
Apatite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Zeolites	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Nepheline	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Calcite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Titanite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Analcite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Noselite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Opal	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Epidote	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Undif. mafics in groundmass	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

[2] John T. Lonsdale, Bureau of Economic Geology, The University of Texas.

(P) = Phenocrysts only.

Item No.—

1. East of mountain with elevation 4,500 feet, northeast corner of Terlingua quadrangle.
2. Lava about 100 yards south of Boot Spring (K, 16).
3. Lone Peak, basin of the Chisos Mountains (L, 16).
4. Top of Chisos Mountains; collected by R. T. Hill.
5. East tank in the Solitario, Terlingua quadrangle.
6. South side Burro Spring intrusion (K, 12).
7. Top of Emory Peak, Chisos Mountains (K, 16).
8. Mountain with elevation 4,500 feet, northeast corner of Terlingua quadrangle.
9. Southwest flank of Pulliam Peak (M, 16).
10. Dike, southwestern Chisos Mountains (G, 11).
11. Dikelike mass, southwestern Chisos Mountains (G, 11).
12. Sill north of Government Spring laccolith (O, 17).
13. Top of Ward Mountain (L, 15).
14. Top of northern Chisos Mountains (Pulliam Peak?); collected by R. T. Hill.
15. Southwest peak of the Solitario, Terlingua quadrangle.
16. Tortuga Mountain (H, 17).

TABLE 14—(Continued)

Item No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Field No.		746F	596F	632B	272A	18B	198B	115B	783C	767A3	667E		668F		783B	213
Lab. Ref. No.		55068	794	55066	55065	56232	55050	56215	56199	55049	55067		800		56198	797
								CHEMICAL ANALYSES								
Analyst	D	A	A	A	A	A	A	A	A	A	A	E	A	D	A	A
Specific gravity		2.65	2.64	2.64	2.63	2.40	2.66	2.68	2.65	2.63	2.65	....	2.71	....	2.64	2.66
SiO_2	74.35	74.13	74.10	73.59	73.57	70.29	69.91	69.82	69.56	68.97	68.44	68.25	68.16	68.13	67.96	67.37
Al_2O_3	12.82	11.82	11.04	11.78	12.66	12.15	13.93	12.47	13.80	13.78	14.68	13.60	13.50	16.00	13.93	13.05
Fe_2O_3	1.37	2.01	2.63	3.03	2.07	1.08	3.00	0.84	3.44	2.32	3.02	3.66	3.12	1.92	3.66	4.70
FeO	0.82	1.36	1.51	1.00	1.76	1.70	0.82	3.52	0.66	1.46	2.16	1.43	2.25	1.12	1.20	0.85
MgO	0.16	....	0.48	....	..	0.14		0.37	0.18	....	....	0.02	0.06	0.51	0.20	0.08
CaO	0.14	0.34	0.34	0.23	0.42	1.17	0.91	1.83	1.17	1.44	0.69	0.54	0.45	1.31	0.73	1.03
Na_2O	5.19	4.52	4.15	4.40	5.00	3.35	4.90	4.75	4.74	5.18	5.82	6.52	6.16	5.46	5.64	5.60
K_2O	4.36	4.72	4.44	4.84	4.70	1.45	5.55	5.07	4.80	5.25	4.88	4.73	5.10	4.73	4.70	5.25
H_2O+	0.17	....	....	....	....	..	....	....	....	....	.	0.32	....	0.18	..	..
H_2O-	0.06	0.29	0.25	0.56	0.15	1.99	0.16	0.46	0.28	0.71	0.26	0.16	0.08	0.24	0.21	0.15
TiO_2	0.14	0.03	0.36	0.03	0.03	0.21	0.37	0.33	0.32	0.33	0.04	0.26	0.39	0.30	0.30	0.38
ZrO_2	..	....	..	....	..	....	..	....	..	....	.	0.25	....	....	.	..
P_2O_5	0.02	0.02	0.39	0.02	0.03	0.01	0.04	0.05	0.05	0.05	0.03	0.02	0.08	0.12	0.05	0.06
MnO	....	0.01	0.13	0.01	0.01	0.02	0.12	0.13	0.06	0.12	0.01	0.04	0.09	....	0.06	0.09
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ignition Loss	....	0.41	0.41	0.51	0.08	6.07	0.46	0.28	0.88	0.41	0.41	....	0.41	....	0.99	1.59
Total	99.60	99.66	100.23	100.00	100.48	99.63	100.07	99.92	99.94	100.02	100.44	99.98	99.85	100.02	99.65	100.20

NORMS															
Q	27.48	29.58	32.52	30.06	25.62	31.89	19.50	4.20	21.90	17.46	14.52	14.52	13.82	15.66	16.98	16.02
or	25.58	27.80	26.13	28.36	27.80	8.34	32.80	21.13	28.36	30.58	28.91	27.80	30.02	27.80	27.80	31.14
ab	41.39	34.58	31.96	34.06	39.30	28.30	40.35	41.39	39.82	41.92	48.21	43.49	40.87	45.59	45.06	37.20
an	....	....	....	....	....	5.56	....	14.46	2.22	....	....	....	....	5.56	....	....
di	....	1.24	....	0.25	1.73	....	....	7.88	0.59	1.73	3.23	....	1.18	....	1.08	0.43
hy	1.19	1.06	2.26	....	1.45	2.15	....	....	2.56	....	....	....	3.17	1.20	....	....
ac	....	3.23	2.77	2.77	2.77	....	0.92	....	....	1.85	0.92	10.16	8.78	....	1.85	8.78
wo	....	....	....	0.35	....	....	1.86	....	0.93	2.09	....	1.16	....	....	0.93	1.51
ol	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
mt	0.93	1.03	2.32	3.02	1.62	1.62	1.72	5.34	1.16	2.32	3.94	0.23	....	2.78	3.02	1.86
hm	....	....	....	....	....	....	1.60	0.96	....	....	....	....	....	....	0.96	0.32
il	0.15	....	0.46	....	....	0.46	0.70	2.43	0.61	0.61	....	0.46	0.76	0.46	0.61	0.76
ap	0.34	....	1.34	....	....	....	....	1.34	....	....	....	....	0.34	1.01	....	0.34
ru	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
calcite (cc)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
pf or ns	....	....	....	....	....	....	....	....	....	....	....	....	0.24ns	....	....	....
th	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ne	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ti	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	13.86	....	....	....	....	....	....	....	....	....	....
MODES																
Quartz	16.8	....	....	....	....	....	....	17.0	....	17.0	....	....	....	3.9	....	....
Qtz.-feld. gm.	....	....	....	....	....	....	....	....	....	....	....	....	....	38.0	....	....
Sodic orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	S	....	....
Alkali feldspar	76.0	....	....	....	....	....	....	61.0	....	61.0	....	....	....	34.9	....	....
Kind of alk. feld.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Plagioclase	....	....	....	....	....	....	....	....	....	....	....	....	....	20.0	....	....
Kind of plagioclase	....	....	....	....	....	....	....	....	....	....	....	....	....	Ao	....	....
Augite	....	....	....	....	....	....	....	....	....	....	....	....	....	0.8	....	....
Aegirine-augite	....	....	....	....	....	....	....	8.0	....	8.0	....	....	....	....	....	....
Aegirine	tr	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Riebeckite	7.2	....	....	....	....	....	....	tr	....	tr	....	....	....	....	....	....
Arfvedsonite	tr	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hornblende	....	....	....	....	....	....	....	tr	....	tr	....	....	....	....	....	....
Olivine-serpentine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Biotite	....	....	....	....	....	....	....	1.0	....	....	....	....	....	1.6	....	....
Ores	....	....	....	....	....	....	....	1.0	....	....	....	....	....	0.8	....	....
Zircon	....	....	....	....	....	....	....	tr	....	....	....	....	....	....	....	....
Fluorite	tr	....	....	....	....	....	....	tr	....	....	....	....	....	....	....	....
Apatite	....	....	....	....	....	....	....	tr	....	....	....	....	....	tr	....	....

TABLE 14—(Continued)

Item No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Field No.		746F	596F	632B	272A	18B	198B	115B	783C	767A3	667E		668F		783B	213
Lab. Ref. No.		55068	794	55066	55065	56232	55050	56215	56199	55049	55067		800		56198	797
Zeolites	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nepheline	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Calcite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Titanite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Analcite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Noselite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Opal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Epidote	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Undif. mafics in groundmass	....	....	....	....	....	....	....	8.0	....	....	....	....	....	....	....	....

S = Sanidine.
Ao = Albite-orthoclase.

Item No.—
17. Mountain with elevation 4,638 feet, north edge, Terlingua quadrangle.
18. Lava from top of Kit Mountain (J, 11).
19. Lava from top of Burro Mesa (L, 12).
20. High lava-capped ridge in southwestern Chisos Mountains (G, 11).
21. Trap Mountain, southwestern Chisos Mountains (H, 12).
22. Small, thin, glassy sill at north end of Mariscal Mountain (E, 19).
23. Northeastern part of Pulliam Peak (M, 17).
24. McKinney Hills northeast of Roy Peak (P, 24).
25. Western flank of Lost Mine Peak (M, 17).
26. Western flank of Vernon Bailey Peak (M, 15).
27. Dike, west side of Lost Mine Peak (L, 17).
28. Top of the Chisos Mountains; collected by R. T. Hill.
29. Southern cap rock face at Casa Grande (L, 16).
30. Wildhorse Mountain, Terlingua quadrangle.
31. High western slope, near top of Lost Mine Peak (M, 17).
32. Western edge of Toll Peak (L, 16).

TABLE 14—(Continued)

Item No.	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Field No.	685B	689G	475B	620K	61B	340B	61B		623I	274B		696B-1	B289CR	116A	100B	747C
Lab. Ref. No.	55012	795	55007	55015		56217			55014	56202		55016	R1460	R1339	R1336	55011
								CHEMICAL ANALYSES								
Analyst	A	A	A	A	D	A	C	D	A	A	D	A	C	C	C	A
Specific gravity	2.67	2.65	2.64	2.66	....	2.69	....	....	2.69	2.65		2.71	....	....	....	2.62
SiO_2	67.35	65.84	65.08	65.08	64.75	64.16	63.63	63.42	63.05	62.92	62.87	62.86	62.84	62.80	62.76	62.19
Al_2O_3	15.01	15.58	15.41	15.08	15.29	14.14	16.68	16.02	15.71	14.80	14.55	14.61	15.84	15.44	14.87	15.20
Fe_2O_3	4.20	4.96	4.36	5.24	5.41	4.32	3.62	3.23	5.33	3.37	5.89	5.68	1.63	2.51	3.88	5.89
FeO	0.40	0.76	1.52	0.46	0.22	1.90	0.57	2.69	0.38	2.68	0.08	1.36	4.82	4.16	1.84	0.58
MgO	0.09	0.11	0.18	0.21	0.11	0.23	0.45	0.16	0.64	0.54	0.20	0.57	0.51	0.33	0.06	0.56
CaO	0.99	0.95	1.54	0.91	0.39	1.27	1.26	1.63	2.58	2.34	2.68	1.99	2.43	2.34	1.70	2.43
Na_2O	5.30	5.15	4.26	5.56	5.13	5.58	5.76	6.12	4.84	4.00	4.63	5.36	4.45	4.59	6.17	5.25
K_2O	5.50	5.25	5.66	5.71	5.25	5.12	5.52	5.30	5.17	5.36	5.25	5.67	5.56	5.44	5.06	5.16
H_2O+	....	....	....	....	1.20	....	0.54	0.34	....	....	1.01	....	0.38	0.65	0.72	....
H_2O-	0.41	0.24	0.41	0.59	0.33	1.23	0.59	0.48	0.53	0.68	0.08	0.35	0.15	0.46	1.04	0.83
TiO_2	0.38	0.43	0.49	0.38	0.35	0.43	0.37	0.36	0.74	0.61	0.54	0.58	0.74	0.62	0.38	0.38
ZrO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.27	0.03	0.10	0.04	0.05	0.06	0.15	0.06	0.24	0.15	0.11	0.10	0.24	0.15	0.04	0.27
MnO	0.04	0.15	0.12	0.12	....	0.20	0.16	....	0.16	0.17	....	0.15	0.18	0.19	0.11	0.09
SO_3	....	....	....	....	....	....	0.19	....	....	....	....	....	....	....	0.66	....
CaO_2	....	....	....	....	....	....	0.16	....	....	....	....	....	....	0.20	0.53	....
Ignition Loss	0.58	0.90	1.08	1.07	....	1.74	....	....	1.18	1.92	....	0.91	....	....	....	0.99
Total	100.52	100.35	100.21	100.45	99.95	100.38	99.65	99.81	100.55	99.52	99.74	100.19	99.77	99.88	99.82	99.82

TABLE 14—(Continued)

Item No.	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Field No.	685B	689G	475B	620K	61B	340B	61B		623I	274B		696B-1	B289CR	116A	100B	747C
Lab. Ref. No.	55012	795	55007	55015		56217			55014	56202		55016	R1460	R1339	R1336	55011
NORMS																
Q	14.69	14.22	15.24	10.02	14.70	11.12	7.50	5.16	10.50	14.27	15.18	7.50	8.10	9.36	9.84	8.58
or	32.80	30.58	33.92	33.92	30.58	30.02	32.80	31.14	30.58	31.14	31.14	33.36	32.80	32.25	30.02	30.02
ab	44.54	43.49	36.15	45.59	42.97	44.01	47.16	51.35	40.35	34.06	38.77	45.06	37.73	38.77	47.16	44.01
an	0.38	4.17	5.84	....	1.39	....	4.17	0.83	6.12	6.67	0.56	....	6.67	5.28	0.56	3.06
di	0.22	....	0.65	1.08	....	1.71	....	4.31	3.46	3.22	0.50	3.03	6.20	3.51	0.71	3.03
hy	....	0.20	0.10	....	0.20	....	1.10	....	....	1.03	....	....	5.78	3.80	....	....
ac	....	....	....	0.92	....	2.77	....	....	....	....	....	....	....	....	....	....
wo	0.70	....	....	1.28	....	1.63	....	0.58	0.58	....	....	2.09	....	....	0.93	1.74
ol	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
mt	0.46	1.62	3.71	0.93	....	5.10	1.16	4.64	....	4.87	....	2.78	2.32	3.71	5.57	....
hm	4.16	3.84	1.92	4.32	5.44	....	2.72	....	5.28	....	5.76	3.68	....	....	....	5.92
il	0.76	0.76	0.91	0.61	0.46	0.76	0.76	0.76	1.06	1.22	0.15	1.22	1.37	1.22	0.76	1.37
ap	0.67	....	0.34	....	0.17	....	0.34	0.34	0.34	0.34	....	0.34	0.34	0.34	....	0.34
ru	....	....	....	....	0.08	....	....	....	....	....	....	....	....	....	....	....
calcite (cc)	....	....	....	....	....	....	0.40	....	....	....	4.10	....	....	0.50	1.20	....
pf or ns	....	....	....	....	....	....	....	....	....	....	0.58pf	....	....	....	....	....
th	....	....	....	....	....	....	0.43	....	....	....	....	....	....	....	1.28	....
ne	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ti	....	....	....	....	....	....	....	....	0.24	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	2.04	....	....	....	....	....
MODES																
Quartz	....	....	....	....	2.0	....	3.0	tr	....	....	5.4	....	4.5	11.0	0.9	....
Qtz.-feld. gm.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	83.5
Sodic orthoclase	....	....	....	....	86.0	....	....	80.2	....	....	80.3	....	59.5	....	....	....
Orthoclase	....	....	....	....	tr (P)	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	....	....	....	tr (P)	....	....	....	....	....
Alkali feldspar	....	....	....	....	....	....	85.0	....	....	....	....	....	....	78.0	86.6	....
Kind of alk. feld.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Plagioclase	....	....	....	....	....	....	tr	....	....	....	tr (P)	....	20.8	tr	....	14.9
Kind of plagioclase	....	....	....	....	....	....	....	....	....	....	albite	....	An_{17}	An_{28}	....	An_{16}
Augite	....	....	....	....	....	....	....	....	....	....	....	....	3.8	4.0	....	0.8
Aegirine-augite	....	....	....	....	....	....	4.5	19.8	....	....	14.3	....	....	....	....	....
Aegirine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	0.8	....
Riebeckite	....	....	....	....	....	....	....	tr	....	....	....	....	....	....	11.6	....
Arfvedsonite	....	....	....	....	....	....	....	tr	....	....	....	....	....	....	....	....

Olivine-serpentine													2.2	3.0		
Hornblende							0.5						6.6	2.0		
Biotite													tr			
Ores					tr		7.0	tr					2.6	2.0	0.1	0.8
Zircon																
Fluorite																
Apatite													tr	tr		
Zeolites																
Nepheline																
Calcite															tr	
Titanite																
Analcite																
Noselite					3.0?											
Opal					3.0											
Epidote					6.0											
Undif. mafics in groundmass																

(P) = Phenocrysts only.

Item No.—

33. Southern end of Lost Mine Peak (M, 18).
34. Eastern part of South Rim Mesa (K, 16).
35. Lower slopes of Pine Canyon, northeast of Crown Mountain (L, 18).
36. Canyon extending northeast from near Mule Ear Spring (H, 13).
37. Intrusion three-fourths mile south of B.M. 3049, Terlingua quadrangle.
38. Sill south of Christmas Mountains (P, 12).
39. The north side of the easternmost of two intrusions on Burro Mesa (L, 12).
40. Mountain with elevation 3,513 feet northwest of Payne's waterhole, Terlingua quadrangle.
41. Lava in mountain ridge extending northwest from Punta de la Sierra (G, 14).
42. Intrusion southeast of the Christmas Mountains (P, 13).
43. Intrusion north of Mud Spring, Terlingua quadrangle.
44. Top of a sugarloaf-shaped mountain southwest of Emory Peak (H, 14).
45. Rosillos Mountains.
46. McKinney Hills, between Roys Peak and Banta Shut-In (O, 23).
47. Sill, east of fault, southwest flank of Christmas Mountains (P, 7, on inset map).
48. West flank of Round Mountain, 25 feet above base (G, 12).

TABLE 14—(Continued)

Item. No.	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
Field No.	576B	628K	746H	577B	47B	241A	565C	241D	726B		727C	700F	653B			42B
Lab. Ref. No.	798	55008	55018	793	R1163	56204	55006	56212	55005		55013	55021	55019			56206
							CHEMICAL ANALYSES									
Analyst	A	A	A	A	B	A	A	A	A	D	A	A	A	D	D	A
Specific gravity	2.74	2.69	2.70	2.70	....	2.62	2.71	2.59	2.68	....	2.66	2.70	2.69	....	....	2.73
SiO_2	61.94	61.93	61.74	61.38	61.28	61.02	60.99	60.68	60.57	60.35	60.20	59.80	59.63	59.62	59.31	56.18
Al_2O_3	14.38	15.89	14.96	16.12	18.75	18.26	16.83	18.30	15.18	16.12	14.23	14.50	16.01	17.89	17.94	17.17
Fe_2O_3	5.90	6.26	6.43	5.04	1.81	1.76	6.87	1.76	5.89	2.00	6.66	6.66	5.60	3.97	2.33	4.62
FeO	1.86	0.96	0.92	1.48	1.53	1.86	....	1.54	1.66	1.87	1.16	1.28	0.94	1.83	1.95	2.78
MgO	0.08	0.34	0.65	0.86	0.40	1.00	0.51	0.63	0.79	0.23	1.15	1.39	1.45	0.75	1.53	1.77
CaO	1.95	1.63	2.99	4.15	1.24	1.89	2.51	1.48	3.13	4.15	3.48	4.44	3.33	2.78	3.58	5.33
Na_2O	5.89	5.54	4.70	4.00	6.18	5.34	4.89	5.83	4.54	6.87	4.50	3.91	3.56	6.20	6.06	4.94
K_2O	5.71	5.50	4.97	3.32	6.56	6.06	4.93	7.40	4.79	5.02	4.24	3.90	4.76	4.55	4.15	3.64
H_2O+	....	....	....	....	0.94	....	....	....	....	0.24	....	....	....	0.71	0.45	....
H_2O-	0.65	0.49	0.45	0.86	0.08	0.16	0.50	0.15	0.73	0.15	0.88	0.57	0.81	0.38	0.41	0.28
TiO_2	0.48	0.49	0.98	1.50	0.67	0.79	1.04	0.75	1.06	0.15	0.98	1.70	1.39	0.66	1.11	1.33
ZrO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.08	0.11	0.25	0.09	0.11	0.12	0.22	0.11	0.34	0.02	0.37	0.43	0.47	0.26	0.48	0.47
MnO	0.13	0.18	0.17	0.10	0.07	0.07	0.10	0.06	0.17	....	0.11	0.11	0.15	....	....	0.14
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	2.86	....	....	....	....	0.75	....
Ignition Loss	0.83	1.23	1.08	0.74	....	1.46	0.94	1.42	1.57	....	1.82	1.12	1.52	....	....	0.47
Total	99.88	100.55	100.29	99.64	99.62	99.79	100.33	100.11	100.42	100.03	99.78	99.81	99.62	99.60	100.05	99.12

TABLE 14—(Continued)

NORMS																
Q	5.58	6.12	10.20	16.38		1.98	9.36		10.38	0.38	11.40	13.80	13.08	1.02	2.16	3.96
or	33.92	32.80	29.47	19.46	38.92	35.58	28.91	43.92	28.36	30.02	25.02	22.80	28.36	26.69	24.46	21.13
ab	41.92	46.63	38.92	34.06	47.16	44.54	41.39	39.30	38.25	54.49	38.25	33.01	29.87	52.40	50.83	41.39
an	....	2.22	5.00	16.12	3.89	8.06	9.45	1.67	6.95	....	5.84	10.56	12.79	7.51	9.45	14.46
di	0.43	1.73	3.46	2.81	0.89	0.46	0.43	3.49	4.10	0.71	6.26	6.26	....	3.46	....	6.48
hy	....	....	....	0.80	....	2.93	....	....	....	2.64	....	0.79	3.60	0.40	3.80	1.40
ac	6.93	....	....	....	....	....	....	....	....	2.77	....	....	....	....	....	....
wo	3.36	1.16	1.97	....	....	....	0.23	0.23	0.46	....	0.58	....	....	....	....	....
ol	....	....	....	....	0.66	....	....	....	....	....	....	....	....	....	....	....
mt	4.64	2.32	0.46	0.46	2.55	2.55	....	2.55	2.55	1.62	1.16	....	....	3.94	3.02	5.57
hm	0.32	4.64	6.08	4.64	....	....	6.24	....	4.16	....	5.76	6.72	5.60	1.28	0.16	0.80
il	0.91	0.91	1.67	2.89	1.37	1.52	1.37	1.37	2.13	1.15	1.82	2.89	2.13	1.22	2.13	2.43
ap	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.67	0.67	0.67	1.01	1.34	0.67	1.34	1.34
ru	....	....	....	....	....	....	....	....	....	....	....	....	0.24	....	....	....
calcite (cc)	....	....	....	....	....	....	....	....	....	6.50	....	....	....	....	1.60	....
pf or ns	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
th	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ne	....	....	....	....	....	....	....	5.40	....	....	....	....	....	....	....	....
ti	....	....	....	....	....	....	0.78	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
MODES																
Quartz	....	....	....	....	....	....	....	....	....	0.9	....	....	....	....	....	....
Qtz.-feld. gm.	....	....	63.5	74.4	....	....	73.3	....	74.6	....	80.0	65.8	....	....	....	....
Sodic orthoclase	....	....	....	....	....	....	....	....	....	81.7	....	....	....	....	....	....
Orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alkali feldspar	....	....	....	....	74.8	....	....	....	....	....	....	....	....	....	45.0	....
Kind of alk. feldspar	....	....	....	....	....	....	....	....	....	....	....	....	....	....	O	....
Plagioclase	....	....	33.8	18.2	7.2	....	21.5	....	22.0	....	17.0	26.7	....	....	46.7	....
Kind of plagioclase	....	....	An_{46}	An_{49}	An_{12-8}	....	An_{42}	....	An_{45}	....	....	An_{49}	....	....	An_{32-9}	....
Augite	....	....	0.3	5.3	....	....	3.9	....	1.7	....	1.3	5.5	....	....	5.1	....
Aegirine-augite	....	....	....	....	2.0	....	....	....	....	....	....	....	....	....	....	....
Aegirine	....	....	....	....	....	....	....	....	....	10.4	....	....	....	....	....	....
Riebeckite	....	....	....	....	....	....	....	....	....	tr	....	....	....	....	....	....
Arfvedsonite	....	....	....	....	....	....	....	....	....	7.0	....	....	....	....	....	....

Item. No.	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
Field No.	576B	628K	746H	577B	47B	241A	565C	241D	726B		727C	700F	653B			42B
Lab. Ref. No.	798	55008	55018	793	R1163	56204	55006	56212	55005		55013	55021	55019			56206
Hornblende	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Olivine-serpentine	....	....	....	....	....	....	....	....	0.2	....	0.4	....	....	....	tr	....
Biotite	....	....	....	....	1.4	....	....	....	....	....	....	....	....	....	0.5	....
Ores	....	....	1.8	2.1	2.6	....	1.3	....	1.5	....	1.3	2.0	....	....	2.7	....
Zircon	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Fluorite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Apatite	....	....	....	....	tr	....	....	....	....	....	....	....	....	....	tr	....
Zeolites	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Nepheline	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Calcite	....	....	....	....	....	....	....	....	....	tr	....	....	....	....	tr	....
Titanite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	tr	....
Analcite	....	....	....	....	12.0	....	....	....	....	....	....	....	....	....	....	....
Noselite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Opal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Epidote	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Undif. mafics in groundmass	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

O = Orthoclase.

Item No.—

49. Southern face of the South Rim (K, 16).
50. Canyon northeast from Punta de la Sierra (F, 15).
51. Lava from Kit Mountain (J, 11).
52. Lava from bottom of cap rock, north side of Tule Mountain (L,12).
53. Northwest flank of Rattlesnake Mountain (L, 8).
54. Western face of Rattlesnake Mountain (L, 8).
55. Canyon northeast of Mule Ear Spring (H, 13).
56. Top of Rattlesnake Mountain (L, 8).
57. Lava from northeast flank of Triangulation Mountain, 125 feet above base (E, 12).
58. Sill-like mass about 1 mile southeast of mountain with elevation 3,420 feet, east edge of Terlingua quadrangle.
59. High lava ledge, north bank of Smoky Creek, 175 feet above base (F, 13).
60. Lava on north end of Burro Mesa (L-M, 13).
61. Lava on northwest flank of Pulliam Peak.
62. Sawmill Mountain, east-central part of Terlingua quadrangle.
63. Southeast flank of the Solitario.
64. West flank of Dominguez Mountain (J, 16).

TABLE 14—(Continued)

Item No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Field No.	726F		247	857C	857H	47D	576F	249	258		877B	726H	582A	727D	86	645C
Lab. Ref. No.	55017		56208	56233	56209	56210	799	56207	R1151		56224	55010	55053	55020	56228	55009
							CHEMICAL ANALYSES									
Analyst	A	D	A	A	A	A	A	A	B	D	A	A	A	A	A	A
Specific gravity	2.76		2.78	2.85	2.80	2.74	2.93	2.80	...	...	2.74	2.85	2.84	2.80	2.85	2.81
SiO_2	55.96	55.48	55.31	55.07	55.06	54.81	54.37	54.05	53.34	52.98	52.91	52.50	51.94	51.89	51.59	51.39
Al_2O_3	15.78	17.57	17.56	17.06	16.21	16.67	13.98	18.62	19.40	18.01	16.85	15.01	14.95	14.96	17.17	16.18
Fe_2O_3	7.29	2.06	5.28	4.60	3.59	3.63	9.10	4.55	2.00	2.26	3.38	9.35	3.84	8.72	17.40	7.94
FeO	2.88	4.89	2.42	5.20	5.88	4.10	2.50	3.86	5.97	5.54	5.32	2.56	5.68	2.58	7.86	2.04
MgO	1.62	2.41	2.00	2.72	2.70	2.61	3.06	1.94	1.53	1.85	1.64	1.81	5.03	2.51	3.81	1.64
CaO	5.20	3.84	5.35	5.95	6.01	4.78	6.98	5.22	6.41	4.35	5.72	6.66	8.19	6.79	6.89	8.35
Na_2O	4.05	5.68	4.66	3.92	3.85	5.23	3.72	5.08	4.79	6.44	5.08	3.90	4.90	3.62	4.48	3.89
K_2O	3.27	3.96	3.86	1.45	2.62	4.20	2.26	3.36	2.96	3.89	3.37	2.84	1.68	2.93	2.37	2.89
H_2O+	...	0.89	....	....	....	....	....	....	0.32	....	....	....	....	....	....	....
H_2O-	0.83	0.33	0.28	0.79	0.83	0.23	0.47	0.26	0.16	0.24	0.70	1.07	1.44	1.47	0.28	0.74
TiO_2	1.77	1.57	1.77	2.00	2.17	2.26	2.00	2.01	1.72	1.64	2.74	1.74	1.37	1.76	2.52	1.97
ZrO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.50	0.95	0.58	0.41	0.47	0.29	0.45	0.63	0.78	0.54	0.73	0.53	0.30	0.52	0.58	0.44
MnO	0.17	....	0.17	0.15	0.15	0.16	0.18	0.14	0.14	....	0.15	0.23	0.15	0.12	0.16	0.24
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Ignition loss	1.19	....	0.40	0.41	0.21	1.23	1.21	0.26	....	....	1.50	2.01	0.78	2.33	0.44	2.75
Total	100.06	99.63	99.64	99.73	99.75	100.20	100.28	99.98	99.52	100.19	100.09	100.21	100.25	100.20	99.87	100.46

NORMS

Q	9.72	....	2.58	10.56	6.84	..	9.18	0.30	....	....	....	6.78	....	6.60	....	2.76
or	18.90	23.35	22.24	8.34	15.57	25.02	13.34	19.46	17.79	22.80	19.46	16.68	10.01	17.24	13.90	17.24
ab	34.06	45.59	39.30	33.01	31.96	39.82	31.44	42.97	40.35	35.46	42.44	33.01	37.20	30.39	36.68	33.01
an	15.57	10.84	15.85	25.02	19.46	9.45	14.73	18.07	22.52	8.90	13.62	15.01	13.90	16.12	19.46	18.35
di	5.18	2.29	5.40	1.33	5.34	9.66	13.18	3.27	3.03	8.10	8.37	9.72	19.92	10.80	9.15	8.86
hy	1.06	....	2.50	8.81	8.12	....	1.50	3.40	2.12	....	....	....	....	1.30	....	....
ac	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
wo	....	....	....	....	....	....	....	....	....	5.53	....	0.70	....	....	....	3.71
ol	....	7.04	....	....	..	2.02	..	....	4.98	....	2.04	....	5.90	....	10.20	....
mt	4.41	3.02	3.02	6.73	5.34	5.34	3.02	6.50	3.02	3.25	4.87	3.94	5.57	3.94	2.55	1.62
hm	4.16	....	3.20	....	..	....	7.04	....	....	....	....	6.56	....	5.92	....	6.72
il	3.34	2.89	3.34	3.80	4.10	4.26	3.80	3.80	3.19	2.89	5.17	3.19	2.58	3.34	4.71	3.65
ap	1.34	2.02	1.34	1.01	1.34	0.67	1.01	1.34	2.02	1.01	1.68	1.34	0.67	1.34	1.34	1.01
ru	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
calcite (cc)					....	....	....	....	....	....	....	....	....	....	....	....
pf or ns	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
th	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ne	....	1.14	....	....	....	2.27	....	....	....	9.94	....	....	2.27	....	0.85	....
ti	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	..	....	....	....	....	....	....

MODES

Quartz	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Qtz.-feld. gm.	58.1	....	....	....	....	....	....	....	....	....	....	56.9	....	58.5	..	43.8
Sodic orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alkali feldspar	....	71.3	....	....	..	....	....	60.0	35.4	50.9	....	....	....	....	....	....
Kind of alk. feld.	....	An	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Plagioclase	31.1	10.0	....	39.0	25.0	..	....	20.0	46.0	15.0	....	31.4	....	31.4	....	42.4
Kind of plagioclase	....	An_{40-24}	....	An_{54}	..	....	....	An_{44}	An_{46}	An_{52-44}	....	....	....	....	....	....
Augite	4.5	2.6(A)	....	5.0	6.0	....	....	11.0	8.4	7.4	....	4.8	....	4.9	....	7.5
Aegirine-augite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Aegirine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Riebeckite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arfvedsonite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hornblende	....	....	....	....	4.0	....	....	2.0	tr	....	....	....	....	....	....	....
Olivine-serpentine	3.3	2.6	....	4.0	....	....	....	....	4.6	2.4	....	4.6	....	3.6	....	5.2
Biotite	....	4.0	....	....		....	....	tr	2.2	0.2	....	....	....	....	....	....
Ores	3.0	6.1	....	2.0	3.0	....	....	7.0	3.4	2.6	....	2.3	....	1.6	....	1.1
Zircon	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Fluorite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Apatite	....	tr	....	tr	..	..	.	tr	....	0.4	....	....	....	....	....	....

TABLE 14—(Continued)

Item No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Field No.	726F		247	857C	857H	47D	576F	249	258		877B	726H	582A	727D	86	645C
Lab. Ref. No.	55017		56208	56233	56209	56210	799	56207	R1151		56224	55010	55053	55020	56228	55009
Zeolites	....	....	....	....	....	....	....	....	....	9.1	....	....	....	....	....	....
Nepheline	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Calcite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Titanite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Analcite	....	3.4	....	....	....	....	....	....	....	12.0	....	....	....	....	....	....
Noselite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Opal	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Epidote	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Undif. mafics in groundmass	....	....	....	49.0	62.0	....	....	....	....	....	....	....	....	....	....	....

An = Anorthoclase.
(A) = Aegiritic rims.

Item No.—
65. Cap rock on Triangulation Mountain, west of Smoky Creek (E,12).
66. Solitario, Terlingua quadrangle.
67. Dikelike mass on northwest flank of Dominguez Mountain (F, 16).
68. Multiple Dike locality, southwest flank of Dominguez Mountain (F, 16).
69. Multiple Dike locality, southwest flank of Dominguez Mountain (F, 16).
70. Rattlesnake Mountain (L, 8).
71. Lava from face of South Rim (K, 16).
72. Dominguez Mountain (G, 16).
73. Dominguez Mountain (G, 16).
74. About 1 mile southeast of B.M. 3049, Terlingua quadrangle.
75. Dikes southwest of Dominguez Mountain (D, 14).
76. Lava in Triangulation Mountain (E, 12).
77. Lava west of Burro Mesa (K, 10).
78. Smoky Creek south of Triangulation Mountain (E, 12).
79. Short dike in Smallpox Well area (R, 14).
80. Lava in Sierra de Chino, about 1 mile east of Smoky Creek (D, 12).

TABLE 14—(Continued)

Item No.	81	82	83	84	85	86	87	88	89	90	91	92	95	94	95	96
Field No.	176A	87A	47A	724	104	385		89	631C	274A	179	148		676A		
Lab. Ref. No.	R1165	56229	R1101	56219	56231	56220		56230	55055	56214	R1166	R1100		55054		
								CHEMICAL ANALYSES								
Analyst	B	A	B	A	A	A	D	A	A	A	B	B	D	A	D	D
Specific gravity	....	2.83	....	2.97	2.87	2.95	....	2.90	2.82	2.85	....	....	....	2.86	....	....
SiO_2	51.31	51.28	50.96	50.21	49.94	49.93	49.80	49.54	49.23	48.97	48.10	47.45	47.31	47.18	46.87	46.00
Al_2O_3	17.84	17.82	17.49	16.10	18.09	15.13	18.38	16.85	14.31	17.46	16.79	16.62	16.95	15.91	17.04	15.93
Fe_2O_3	2.51	2.30	2.16	2.72	5.25	3.58	1.84	3.74	7.63	1.09	1.87	2.69	4.88	3.00	3.12	1.85
FeO	7.01	7.84	7.37	9.28	6.68	8.36	7.57	8.02	4.16	9.46	9.72	7.71	4.41	8.20	6.81	7.61
MgO	3.53	2.97	3.73	4.40	4.16	4.32	2.63	4.84	4.48	4.46	4.29	6.63	2.92	5.73	3.35	8.91
CaO	5.79	5.74	6.23	7.79	6.57	8.49	7.09	7.33	9.83	7.09	6.94	8.53	6.10	8.52	7.66	9.28
Na_2O	4.76	4.85	4.81	3.56	4.67	3.40	4.94	3.66	3.40	4.40	4.33	4.37	5.78	4.53	5.13	4.11
K_2O	2.88	2.50	2.71	1.93	2.11	1.61	2.60	1.70	1.07	2.00	2.21	1.36	3.01	1.26	2.39	1.85
H_2O+	0.72	....	0.56	....			1.73	....	....	.	1.31	1.01	4.44	....	2.99	1.38
H_2O-	0.15	0.36	0.18	0.37	0.25	0.73	0.27	0.25	0.71	0.23	0.18	0.23	0.62	0.82	0.21	0.12
TiO_2	2.35	2.30	2.45	3.19	1.32	3.28	2.30	2.93	1.67	3.55	2.98	2.36	2.33	2.30	2.96	2.26
ZrO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.69	0.58	0.89	0.12	0.44	0.39	0.95	0.45	0.34	0.56	0.75	0.95	0.83	0.40	0.93	0.62
MnO	0.17	0.19	0.18	0.19	0.16	0.17	....	0.16	0.20	0.14	0.18	0.17	....	0.20	0.19	....
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	....	....	....	0.42	....	....	....
Ignition Loss	....	10.10	....	0.06	0.24	0.72	....	0.35	2.44	0.20	....	....	....	1.60	....	....
Total	99.71	99.83	99.72	99.71	99.88	100.11	100.10	99.82	99.47	99.61	99.65	100.08	100.00	99.65	99.65	99.92

NORMS

Q	....	....	....	....	....	....	....	....	3.90	....	....	....	....	....	....	....
or	17.24	16.12	16.12	11.12	12.23	11.12	15.57	10.01	6.67	11.68	12.79	7.78	17.79	7.23	14.46	10.56
ab	36.68	35.63	35.63	28.30	36.15	28.82	31.44	30.92	28.82	31.44	29.87	28.82	28.82	27.75	25.68	14.41
an	18.90	17.79	17.79	23.35	22.24	20.29	20.29	24.74	20.29	21.69	20.29	21.96	11.68	19.46	16.40	19.74
di	4.32	6.18	6.18	11.90	6.05	18.40	7.64	7.23	20.52	8.01	8.07	11.25	10.21	16.32	13.14	18.54
hy	....	....	....	11.98	....	7.20	....	10.62	1.07	....	....	....	....	....	....	....
ac	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
wo	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ol	10.05	10.39	10.39	2.14	9.76	1.53	8.34	3.50	....	13.34	13.50	14.10	1.96	11.07	5.11	16.06
mt	3.71	3.25	3.25	3.94	7.66	3.96	2.55	5.34	9.51	1.62	2.78	3.94	6.96	4.41	4.41	2.25
hm	....	....	....	....	....	....	....	....	1.12	....	....	....	....	....	....	....
il	4.56	4.71	4.71	6.08	2.43	6.23	4.41	5.47	3.04	6.69	5.78	4.41	4.41	4.41	5.62	4.10
ap	1.68	2.02	2.02	0.34	1.01	1.68	2.02	1.01	0.67	1.01	1.68	2.35	2.02	1.01	2.02	1.34
ru	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
calcite (cc)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
pf or ns	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
th	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
ne	1.70	2.84	2.84	....	1.70	....	5.40	....	....	3.12	3.41	4.26	10.56	5.96	9.37	10.93
ti	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
C	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

MODES

Quartz	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Qtz.-feld. gm.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sodic orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Orthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Anorthoclase	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Alkali feldspar	56.3	....	}	....	....	....	33.0	....	....	....	25.3	}	34.0	....	20.0	....
Kind of alk. feld.		....	}71.8	....	....	....	O	....	....	....		}31.0	O	....		....
Plagioclase	18.0	....	}	....	....	....	34.7	....	....	....	42.8	}	35.4	....	33.6	40.06
Kind of plagioclase	An_{48}	....	An_{48}	....	....	....	An_{64-56}	....	....	....	An_{54}	An_{48-46}	....	....	An_{59-44}	....
Augite	7.0	....	9.4	....	....	....	11.7(A)	....	....	....	11.6	10.0(P)	18.9	....	8.2	30.7
Aegirine-augite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Aegirine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Riebeckite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Arfvedsonite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Hornblende	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Olivine-serpentine	4.7	....	6.1	....	....	....	9.0	....	....	....	9.7	16.0(P)	2.5	....	4.0	13.9
Biotite	6.2	....	3.6	....	....	....	tr	....	....	....	....	1.0	....	....	1.0	....
Ores	5.6	....	9.1	....	....	....	7.8	....	....	....	8.8	17.0	5.6	....	7.2	14.8
Zircon	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Fluorite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Apatite	1.2	....	....	....	....	....	tr	....	....	....	tr	....	....	....	0.2	....

TABLE 14.—(cont'd.)

Zeolites	----	----	----	----	----	----	tr	----	----	----	----	----	tr	----	1.8	----
Nepheline	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Calcite	----	----	----	----	----	----	----	----	----	----	----	----	tr	----	----	----
Titanite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Analcite	1.0	----	----	----	----	----	3.8	----	----	...	1.8	----	3.6	----	24.0	----
Noselite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Opal	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Epidote	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Undif. mafics in groundmass	----	----	----	----	----	----	----	----	----	----	----	25.0	----	----	----	----

O = Orthoclase.
(A) = Aegiritic rims.
(P) = Phenocrysts only.

Item No.—
81. Peña Mountain (J, 9).
82. Long dike in Smallpox Well area (R, 15).
83. Rattlesnake Mountain (L, 8).
84. Western half of curved intrusion, west of Terlingua Abaja (H, 6).
85. Sill-like mass west of road and south of Maverick Mountain (M, 9).
86. Large tabular mass about 4 miles northwest of Cerro Castellan (H, 8).
87. Mountain with elevation 3,513 feet, Terlingua quadrangle.
88. Tabular mass north of Dripping Spring (P, 15–16).
89. Lava, western slope of Cerro Castellan (G, 10).
90. Large tabular intrusion southeast of the Christmas Mountains (P, 13–14).
91. Small intrusion about ¼ mile south of Maverick Mountain (M, 10).
92. Small sill remnant on Mesa de Anguila, south of Lajitas (K, 1).
93. About 2 miles northeast of mountain with elevation of 3,518 feet, Terlingua quadrangle.
94. Basal lava at Sierra Aguja (J, 6).
95. Cigar Mountain, Terlingua quadrangle.
96. Intrusion near B.M. 2671, near old Terlingua-Alpine road, Terlingua quadrangle.

TABLE 14—(Continued)

Item No.	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
Field No.	174A	386	219	69D		1	589	840B	243A		71B	114	628F	72A	243D	107A	853B	
Lab. Ref. No.	55052	56221	56216	R1164		R1099	55051	56222	56213		56226	R1137	55056	56227	R1167	R1102	56223	
								CHEMICAL ANALYSES										
Analyst	A	A	A	B	D	B	A	A	A	D	A	C	A	A	B	B	A	D
Specific gravity	2.86	2.98	2.98	....	....	....	2.88	2.19	2.83	....	3.02	....	2.97	3.03	....	....	3.19	....
SiO_2	45.78	45.53	45.43	44.99	44.81	44.73	44.44	43.92	43.74	43.65	43.46	43.26	42.84	43.34	41.55	41.29	40.63	40.17
Al_2O_3	18.45	17.74	15.53	16.88	16.81	14.95	15.05	15.28	21.50	13.16	14.38	16.15	12.88	13.78	13.52	13.71	15.54	13.44
Fe_2O_3	4.99	2.25	4.43	3.20	4.06	2.95	5.15	3.25	2.39	3.35	3.85	2.18	11.94	4.08	4.04	3.94	1.55	4.21
FeO	6.26	9.50	8.44	7.72	7.19	9.44	9.16	7.08	6.94	7.00	6.66	11.16	2.80	6.87	7.18	7.38	10.16	5.89
MgO	3.76	5.37	4.92	4.58	4.21	4.69	5.79	9.75	3.42	12.48	10.55	5.25	5.22	12.50	12.32	11.56	10.15	10.23
CaO	11.12	9.36	10.68	7.98	7.21	9.70	9.32	11.57	9.03	12.18	12.32	9.26	10.48	11.44	12.55	13.31	10.19	12.46
Na_2O	3.32	3.18	2.88	4.58	4.65	4.05	3.28	3.10	5.52	2.43	3.08	3.13	3.43	3.00	3.29	2.98	3.50	2.22
K_2O	1.00	1.16	1.08	2.96	1.97	1.40	1.28	1.88	2.57	1.30	1.15	1.43	1.05	0.94	0.71	0.61	1.10	1.45
H_2O+	....	....	....	2.37	3.70	1.44	....	....	....	1.79	....	2.33	....	....	1.47	2.00	....	2.20
$H_2O—$	0.41	0.63	0.28	0.10	1.07	0.25	0.33	0.25	0.35	0.19	0.29	0.60	0.81	0.30	0.20	0.18	0.33	0.66
TiO_2	2.35	3.31	3.68	3.51	3.27	4.20	3.48	1.85	1.51	1.55	1.82	3.76	4.35	1.67	1.89	1.98	4.95	1.67
ZrO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.40	0.50	0.28	0.86	1.04	1.82	0.75	0.56	0.24	0.63	0.44	0.81	1.36	0.52	0.68	0.71	0.09	....
MnO	0.19	0.19	0.17	0.16	....	0.22	0.22	0.20	0.23	....	0.19	0.20	0.25	0.20	0.20	0.21	0.14	....
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	0.10	....	....	....	....	....	....	....	4.61
Ignition Loss	1.46	1.14	1.85	....	....	....	1.30	1.48	2.16	....	1.84	....	1.90	2.30	....	....	1.57	....
Total	99.49	99.86	99.55	99.89	99.99	99.84	99.55	100.17	99.60	99.81	100.17	99.98	99.31	99.94	99.60	99.86	99.90	99.87

TABLE 14.—(Continued)

Item No.	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
Field No.	174A	386	219	69D		1	589	840B	243A		71B	114	628F	72A	243D	107A	853B	
Lab. Ref. No.	55052	56221	56216	R1164		R1099	55051	56222	56213		56226	R1137	55056	56227	R1167	R1102	56223	
NORMS																		
Q																		
or	6.12	7.23	6.67	17.79	11.68	8.34	7.78	11.12	15.01	7.78	6.67	8.34	6.12	5.56	3.89	3.33	6.67	8.34
ab	24.63	24.10	24.10	15.20	26.76	27.25	24.10	4.90	4.19	4.98	5.50	22.53	27.77	5.50	2.10	1.57	1.82	18.34
an	32.25	30.30	26.13	16.68	19.18	18.63	22.24	22.24	26.41	21.13	21.96	25.58	16.68	21.41	20.02	22.24	23.35	22.52
di	16.41	10.30	20.08	14.19	8.07	14.31	15.51	25.15	14.54	28.06	29.00	7.64	18.36	25.16	30.02	31.30	21.87	4.16
hy			0.43															7.06
ac																		
wo																		
ol	6 69	13.74	5.76	7.41	9.11	9.60	10.33	14.35	7.03	18.11	13.46	18.28	3.08	18.72	16.84	15.23	17.39	15.08
mt	7.19	3.25	6.26	4.64	5.80	4.18	7.42	4.87	3.25	4.87	5.57	3.25		6.03	5.80	5.80	2.09	6.03
hm													11.84					
il	4.41	6.23	6.99	6.69	6.08	9.70	6.69	3.50	2.89	2.89	3.50	7.14	6.38	3.04	3.65	3.80	9.42	3.19
ap	1.01	1.34	0.67	2.02	2.35	4.37	1.68	1.34	0.34	1.34	1.01	2.02	3.02	1.34	1.68	1.68		1.68
ru																		
calcite (cc)										0.20								10.50
pf or ns																		
th																		
ne	1.70	1.70		12.78	6.82	3.69	1.99	11.93	23.00	8.37	11.22	2.27	0.57	10.65	13.94	12.78	14.91	
ti													2.35					
C																		
MODES																		
Quartz																		
Qtz.-feld. gm.																		
Sodic orthoclase																		
Orthoclase																		
Anorthoclase																		
Alkali feldspar				39.5	15.00					0.3								
Kind of alk. feld.						18.0						61.1						20.6
Plagioclase				17.4	46.1					12.0					2.3	11.2		
Kind of plagioclase				An_{54-50}	An_{59}	An_{60}				An_{61}		An_{52}			An_{60}	An_{54}		An_{62}
Augite				19.2	11.8	45.0(ol)				38.0		19.6			37.6	56.8		47.0
Aegirine-augite																		
Aegirine																		
Riebeckite																		
Arfvedsonite																		

Hornblende				10.9	tr												tr
Olivine-serpentine					7.2	8.0				21.0		8.3			5.0	14.1		13.9
Biotite				2.3						tr								tr
Ores				7.3	8.1	21.0				3.1		10.4			9.5	10.1		7.6
Zircon																		
Fluorite																		
Apatite				1.0	tr					tr		tr			tr			tr
Zeolites					tr													
Nepheline															16.8			
Calcite																		
Titanite																		
Analcite				11.7	11.8							0.6			1.0			10.9
Noselite																		
Opal																		
Epidote																		
Undif. mafics in groundmass						8.0									27.8	7.9		

(ol) = Includes olivine.

Item No.—

97. Large lava-capped mesa east of Peña Mountain (J, 10).
98. Thin long dike about 2½ miles southwest of Peña Mountain (H, 8).
99. Large hogback sill west of Mariscal Mountain (A–F, 19–20).
100. Bone Springs sill (Q–R, 1).
101. Intrusion about 1 mile northeast of mountain with elevation 3,513 feet, Terlingua quadrangle.
102. Northeastern part of curved intrusive mass west of Terlingua Abaja (J, 6).
103. Basal lava west of Cerro Castellan (G, 9).
104. Circular mass, about 5 miles north of the Chisos Mountains (O, 15).
105. Sill, largest of two intrusions about 1½ miles east of Maverick Mountain (N, 10).
106. Mountain with elevation 3,607 feet, Terlingua quadrangle.
107. Smallpox Well Mountain (P, 14).
108. Basal lava at Dogie Mountain (N, 11).
109. Dominguez Mountain (G, 16).
110. Sill near Smallpox Well (P, 14).
111. Band in sill of largest of two bodies, about 1½ miles east of Maverick Mountain (N, 10).
112. Smaller of two bodies, about 1½ miles east of Maverick Mountain (N, 10).
113. Sill, northern end Chisos Pen anticline (O–P, 12–13).
114. Mass about 1½ miles southeast of mountain with elevation 4,500 feet, Terlingua quadrangle.

TABLE 15.—Chemical analyses and modes of analcite rocks, Big Bend region. (See also table 14.)

Item No.	53	62	66	74	81	87	91	93	95	100	101	111	114
						CHEMICAL ANALYSES							
SiO_2	61.28	59.62	55.48	52.98	51.31	49.80	48.10	47.31	46.87	44.99	44.81	41.55	40.17
Al_2O_3	18.75	17.89	17.57	18.01	17.84	18.38	16.79	16.95	17.04	16.88	16.81	13.52	13.44
Fe_2O_3	1.81	3.97	2.06	2.26	2.51	1.84	1.87	4.88	3.12	3.20	4.06	4.04	4.21
FeO	1.53	1.83	4.89	5.54	7.01	7.57	9.72	4.41	6.81	7.72	7.19	7.18	5.89
MgO	0.40	0.75	2.41	1.85	3.53	2.63	4.29	2.92	3.35	4.58	4.21	12.32	10.23
CaO	1.24	2.78	3.84	4.35	5.79	7.09	6.94	6.10	7.66	7.98	7.21	12.55	12.46
Na_2O	6.18	6.20	5.68	6.44	4.76	4.94	4.33	5.78	5.13	4.58	4.65	3.29	2.22
K_2O	6.56	4.55	3.96	3.89	2.88	2.60	2.21	3.01	2.39	2.96	1.97	0.71	1.45
H_2O+	0.94	0.71	0.89	2.45	0.72	1.73	1.31	4.44	2.99	2.37	3.70	1.47	2.20
$H_2O—$	0.08	0.38	0.33	0.24	0.15	0.27	0.18	0.62	0.21	0.10	1.07	0.20	0.66
CO_2	....	....	....	....	....	....	....	0.42	....	....	....	....	4.61
TiO_2	0.67	0.66	1.57	1.64	2.35	2.30	2.98	2.33	2.96	3.51	3.27	1.89	1.67
P_2O_5	0.11	0.26	0.95	0.54	0.69	0.95	0.75	0.83	0.93	0.86	1.04	0.68	0.66
MnO	0.07	....	....	....	0.17	....	0.18	....	0.19	0.16	....	0.20	....
SO_3	....	....	....	....	....	....	....	....	....	....	....	....	....
Ignition Loss	....	....	....	....	....	....	....	....	....	....	....	....	....
Totals	99.62	99.60	99.63	100.19	99.71	100.10	99.65	100.00	99.65	99.89	99.99	99.60	99.87

Item No.—
53. Analcite syenite sill, northwest flank of Rattlesnake Mountain, Big Bend National Park.
62. Analcitic microsyenite, Sawmill Mountain, east-central part of Terlingua quadrangle.
66. Analcitic microsyenite, Solitario, Terlingua quadrangle.
74. Analcite-plagioclase syenite, about 1 mile southeast of B.M. 3049, Terlingua quadrangle.
81. Analcite andesine syenite, Peña Mountain, Big Bend National Park.
87. Analcite trachybasalt porphyry, mountain with elevation 3,513 feet, Terlingua quadrangle.
91. Analcite syenogabbro sill, small intrusion about ¼ mile south of Maverick Mountain, Big Bend National Park.
93. Analcite syenogabbro, about 2 miles northeast of mountain with elevation 3,518 feet, Terlingua quadrangle.
95. Analcite syenogabbro, Cigar Mountain, Terlingua quadrangle.
100. Analcite labradorite syenite, Bone Springs sill, Big Bend National Park.
101. Analcite trachydolerite, intrusion about 1 mile northeast of mountain with elevation 3,513 feet.
111. Nepheline basalt (?) sill in largest of two bodies, about 1½ miles east of Maverick Mountain, Big Bend National Park.
114. Analcite picritic basalt, about 1-½ miles southeast of mountain with elevation 4,500 feet, Terlingua quadrangle.

MODES

Analcite	12.00	....	3.40	12.00	1.00	3.80	1.80	....	24.00	11.70	11.80	1.00	10.90
Plagioclase	7.20	....	10.00	15.00	18.00	34.70	42.80	....	33.60	17.40	46.10	2.30	20.60
Kind of plagioclase	An_{12-8}	....	An_{40-24}	An_{52-44}	An_{48}	An_{64-56}	An_{54}	....	An_{59-44}	An_{54-50}	An_{59}	An_{60}	An_{62}
Alkali feldspar	74.80	....	....	50.90	56.30	33.00	25.30	....	20.00	39.50	15.00	....	....
Anorthoclase		....	71.30	....	....	....	....	....	....	....	....	....	....
Augite		....		7.40	7.00		11.60	....	8.20	19.20	11.80	37.60	47.00
Aegirine-augite	2.00	....	2.60	....	....	11.70A	....	....	....	....	....	....	....
Aegirine		....		....	....		....	....	....	....	....	....	....
Olivine	....	....	2.60	2.40S	4.70	9.00S	9.70	....	4.00	1.60S	7.20	5.00S	13.90S
Ores	2.60	....	6.10	2.60	5.60	7.80	8.80	....	7.20	7.30	8.10	9.50	7.60
Biotite	1.40	....	4.00	0.20	6.20	tr	....	....	1.00	2.30	tr	....	tr
Hornblende	....	....	....	....	....	....	....	....	....	....	....	....	tr
Apatite	tr	....	tr	0.40	1.20	tr	tr	....	0.20	1.00	tr	tr	tr
Zeolites	....	....	....	9.10	....	tr	....	....	1.80	....	tr	....	....
Nepheline	....	....	....	....	....	....	....	....	....	....	....	16.80	....
Groundmass	....	....	....	....	....	....	....	....	....	....	....	27.80	....
Totals	100.00	....	100.00	100.00	100.00	100.00	100.00	....	100.00	100.00	100.00	100.00	100.00

S = Serpentinized.
A = With aegiritic rims.

TABLE 15 (Continued)— MODES OF ROCKS AT RATTLESNAKE MOUNTAIN AND PEÑA MOUNTAIN

Thin Section No.	1	2	3	4	5	6	7	8
Analcite	6.2	4.3	8.7	12.0	8.1	13.8	1.0	2.4
Alkali feldspar	47.5[a]	47.1[a]	70.0	74.7[b]	84.3	80.3	56.3	49.1
Plagioclase feldspar	13.8 (An_{50-52})	16.5 (An_{48-49})					18.0 (An_{48})	21.0 (An_{54-50})
Augite	10.1	5.1T	7.3	2.0	3.2	1.7	7.0T	10.5T
Aegerine-augite	....	....						
Hornblende	....	....	0.9	....	....	....	....	....
Biotite	4.6	6.4	2.9	1.4	1.5	1.6	6.2	6.2
Olivine	10.2S	13.4S	....	....	....	....	4.7S	6.9S
Ore minerals	7.6	7.2	10.2	2.6	2.7[c]	2.1	5.6	3.9
Apatite	tr	tr	tr	tr	tr	....	1.2	tr
Zeolites	....	....	....	....	....	[d]	....	tr
Totals	100.0	100.0	100.0	100.0	99.8	99.5	100.0	100.0

[a] Orthoclase.
[b] Sodic orthoclase and anorthoclase.
[c] 0.2 calcite.
[d] Trace of later zeolites and 0.5 calcite.

S = Serpentinized.
T = Titaniferous.

Thin Section No.—
1. Analcite-labradorite syenite, Rattlesnake Mountain.
2. Analcite-andesine syenite, Rattlesnake Mountain.
3. Leucocratic analcite-andesine syenite, Rattlesnake Mountain.
4. Analcite syenite, Rattlesnake Mountain.
5. Analcite syenite, Rattlesnake Mountain.
6. Analcite syenite, Rattlesnake Mountain.
7. Analcite-andesine syenite, Peña Mountain.
8. Analcite-labradorite syenite, Peña Mountain.

TABLE 16.—Chemical analyses and modes of syenodiorite-syenogabbro and related rocks, Dominguez Mountain. (See also table 14.)

Item No.	a	b	c	d	e	f	64	67	68	69	72	73	75
Field Sample No.	250	896E	246	896D	890B	890C-2	42B	247	857C	857H	249	258	877B
						CHEMICAL ANALYSES							
SiO_2	71.10	70.80	64.90	62.00	61.80	61.10	56.18	55.31	55.07	55.06	54.05	53.34	52.91
Al_2O_3	13.50	13.00	13.30	17.10	13.10	16.10	17.17	17.56	17.06	16.21	18.62	19.40	16.85
Fe_2O_3	1.41	1.40	4.82	2.06	0.75	3.34	4.62	5.28	4.60	3.59	4.55	2.00	3.38
FeO	0.46	0.88	0.04	3.17	5.20	2.00	2.78	2.42	5.20	5.88	3.86	5.97	5.32
MgO	nd	nd	nd	nd	nd	nd	1.77	2.00	2.72	2.70	1.94	1.53	1.64
CaO	nd	nd	nd	nd	nd	nd	5.33	5.35	5.95	6.01	5.22	6.41	5.72
Na_2O	5.25	3.45	4.35	4.54	4.48	6.12	4.94	4.66	3.92	3.85	5.08	4.79	5.08
K_2O	4.83	5.45	5.13	4.77	4.89	5.53	3.64	3.86	1.45	2.62	3.36	2.96	3.37
H_2O+	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.32	nd
H_2O-	0.16	0.23	0.16	0.18	0.12	0.24	0.28	0.28	0.79	0.83	0.26	0.16	0.70
TiO_2	0.10	0.29	0.34	0.95	0.94	0.35	1.33	1.77	2.00	2.17	2.01	1.72	2.74
P_2O_5	nd	nd	nd	nd	nd	nd	0.47	0.58	0.41	0.47	0.63	0.78	0.73
MnO	nd	nd	nd	nd	nd	nd	0.14	0.17	0.15	0.15	0.14	0.14	0.15
Ignition Loss	0.50	1.25	2.26	0.69	0.02	0.50	0.47	0.40	0.41	0.21	0.26	....	1.50
Totals	97.31	96.75	95.30	95.46	91.30	95.28	99.12	99.64	99.73	99.75	99.98	99.52	100.09

nd = Not determined.

TABLE 16.—(Continued)

Item No.	a	b	c	d	e	f	64	67	68	69	72	73	75
Field Sample No.	250	896E	246	896D	890B	890C-2	42B	247	857C	857H	249	258	877B
						MODES							
Quartz	....	21	....	10	tr	1	....	....	....	....	....	....	....
Alkali feldspar	....	71	....	....	85	94	....	....	....	....	60	34	....
Plagioclase	....		....	....	....		....	....	$39An_{54}$	25	$20An_{44}$	$47An_{44}$	....
Augite	....	....	....	....	9	3	....	....	5	6	11	7	....
Hornblende	....	....	....	....		....	....	....	....	4	2	tr	....
Olivine	....	....	....	....	2	....	....	....	4	....	....	4	....
Biotite	....	8	....	....	....	....	....	....	....	....	tr	3	....
Ores	....	tr	....	....	4	2	....	....	2	3	7	4	....
Apatite	....	tr	....	tr	tr	....	....	....	tr	....	tr	1	....
Zircon	....	tr	....	tr	tr	tr	....	....	....	....	....	....	....
Groundmass	....	....	....	....	....	....	....	....	49	62	....	....	....
Fluorite	....	tr	....	....	....	tr	....	....	....	....	....	....	....
Totals	....	100.0	....	....	100.0	100.0	....	....	99.0	100.0	100.0	100.0	....

a. Porphyritic leucorhyolite mantle.
b. Light rock, gap near top of mountain.
c. Felsite dike, west canyon.
d. Top of Dominguez Mountain.
e. Bald spot on western slope of mountain.
f. Light band on western slope of mountain.
64. West flank of Dominguez Mountain.
67. Trachyandesite porphyry, dikelike mass on northwest flank of Dominguez Mountain.
68. Selvage trachyandesite porphyry at Multiple Dike locality, southwest flank of Dominguez Mountain.
69. Trachybasalt porphyry, composite dike at Multiple Dike locality, southwest flank of Dominguez Mountain.
72. Augite syenite, lower west flank of Dominguez Mountain.
73. Coarse olivine syenodiorite in west canyon of Dominguez Mountain.
75. Dikes southwest of Dominguez Mountain.

STRUCTURAL GEOLOGY

Ross A. Maxwell

Regional Summary

On the west side of the Pecos River is a belt of plains, low mesas, and plateaus 50 to 100 miles wide. Farther west and southwest, in west Texas and southeastern New Mexico, northwest-trending mountains rise above the plains and plateaus and are separated by broad basins. This area, bounded on the northeast by the Pecos River and on the west and southwest by the Rio Grande, is called the Trans-Pecos region.

The structural framework of the Trans-Pecos region has been developed during several periods of tectonic activity. The mountains in the northern part of the region are, for the most part, tilted blocks bounded by faults. The intermontane basins have been filled by detritus from the adjacent highlands. Farther south the area has been more complexly deformed. In some places the bedded rocks have been strongly folded and thrust faulted. Some of the younger structures are concordant with older structures; in other places the younger structures cut across the older trends; there has been renewed movement along some trends. Most sedimentary rocks are tilted, warped, or gently folded. Locally, the sedimentary rocks are intensely deformed by igneous intrusions but these areas are relatively sparse. In some areas the intrusions pierced pre-existing structures and in others they have only domed the sedimentary rocks.

Plate XI shows the principal structural features in Trans-Pecos Texas and northeastern Mexico. Paleozoic rocks of the Ouachita system crop out in the Marathon Basin, Solitario, and Persimmon Gap in southern Trans-Pecos Texas and in the Sierra del Carmen, Coahuila, Mexico. Late Mesozoic structural elements include (1) the Diablo Platform at the northwest, (2) the Coahuila Platform at the southeast, and (3) the Chihuahua Tectonic Belt that borders the Coahuila Platform at the southwest. Tertiary deformation produced mostly fault blocks and broad open folds. Because of inadequate data for Mexico, parts of the map are schematic.

During the Mesozoic Era, great thicknesses of sediments were deposited in the Chihuahua Trough, and during the Laramide orogeny these rocks were compressed into the complex structures of the Chihuahua Tectonic Belt. Most of the folds were overturned toward the northeast and the movement along the thrust faults was in the same direction. The geology of the Chihuahua Tectonic Belt, including the Eagle, Quitman, and Malone Mountains, has been described by Baker (1928, 1930a, 1935), Darton (1933), P. B. King (1935), Albritton (1938), Smith (1940, 1941), Humphrey (1956), DeFord (1958), and Underwood (1962, 1963).

The Coahuila Platform lies east of the Chihuahua Tectonic Belt and the Cretaceous sea moved over the Platform as its waters overflowed the Chihuahua Trough. Cretaceous rocks on the Coahuila Platform are normally less complexly deformed than those in the Chihuahua Tectonic Belt. They crop out in the Chinati Mountains in southwestern Presidio County but are more extensive in the Terlingua uplift and the Big Bend area in Brewster County (Pl. XI). In the Chinati Mountains, the Comanchean formations form the periphery of the mountains where they rest on Pennsylvanian and Permian rocks. The stratigraphic sequence is not complete at most places because of overlapping Tertiary volcanic rocks and normal faults. Only one thrust fault has been described.

The principal elements of the structure have been discussed by Udden (1904), Baker (1927, 1929, 1935), P. B. King (1935), Skinner (1940), Ross (1943), Rix (1953), and Amsbury (1957).

Pre-Mesozoic rocks in southern Trans-Pecos Texas are part of the Ouachita system (Flawn et al., 1961); the rocks are highly deformed in the Marathon and Solitario areas, in the Persimmon Gap—Dog Canyon area in Big Bend National Park, and at the base of the Sierra del Carmen southeast of Boquillas in Coahuila, Mexico. Farther north, in the Paleozoic foreland basins, the rocks are relatively undeformed.

The Marathon Basin comprises about 1,200 square miles of low mountains, hills, and plains. Strongly folded and faulted Paleozoic rocks form sharp northeast-trending hogbacks and long sinuous ridges. The Paleozoic rocks are rimmed by escarpments of Cretaceous rocks on the west, south, and east, and by escarpments of Permian and Cretaceous rocks on the north. The geology of the area has been described by Hill (1900), Udden (1907a), Baker and Bowman (1917), P. B. King (1931, 1937), Eifler (1943), Graves (1954), J. L. Wilson (1954a, 1954b), Fan and Shaw (1956), Berry (1958), Berry and Nielsen (1958), and Flawn et al. (1961).

The Solitario is a circular uplift 9 miles in diameter, about 35 miles southwest of the western rim of the Marathon Basin. Northeast-southwest-trending, strongly deformed Paleozoic rocks in the center of the uplift are completely encircled by a high-dipping rim of Cretaceous rocks. Part of the central basin is floored by Tertiary volcanic rocks. The geology of the Solitario area has been described by Udden (1907b), Powers (1921), Sellards (1933), Baker (1935), Lonsdale (1940), J. L. Wilson (1954a), Herrin (1959), and Flawn et al. (1961).

Ouachita facies rocks in the Persimmon Gap—Dog Canyon area crop out about 10 miles south of the southernmost exposures of Paleozoic rocks in the Marathon Basin and about 45 miles east-northeast of the Solitario. The rocks occur in separated thrust slices along northwest-southeast-trending ridges in the southern end of the Santiago Mountains. The geology of the area has been described by Maxwell et al. (1949, pp. 27–28), J. L. Wilson (1954a), Lonsdale et al. (1955, pp. 54–59 and map), Hazzard et al. (1958), Berry and Nielsen (1958), and Flawn et al. (1961).

Pre-Cretaceous rocks of the Ouachita facies crop out at the foot of the high Sierra del Carmen escarpment near Boquillas, Coahuila, Mexico, immediately south of Big Bend National Park. They were first recognized by Baker (Böse, 1923, p. 133; Baker, 1935, p. 146); they were studied by Flawn and Maxwell (1958), and described in more detail by Flawn et al. (1961, p. 99). The rocks have been subjected to low-grade metamorphism. Age determinations suggest that the metamorphism took place during Paleozoic time; the rocks are probably early to middle Paleozoic (Flawn et al., 1961, pp. 81, 99).

Big Bend National Park

GENERAL FEATURES

The Sierra del Carmen in Texas and the southern Santiago Mountains form part of a structural and topographic highland along the eastern boundary of Big Bend National Park. Farther west, Mesa de Anguila, an elevated fault block, forms a highland along the western boundary, which is continued northward into the Terlingua monocline and at the Solitario. In the central Park area, between the Mesa de Anguila-Terlingua monocline-Solitario uplifts on the west and the Sierra del Carmen in Texas and the Santiago Mountains toward the east, is an elongate area that is, for the most part, structurally lower than the highland belts on either side and in part topo-

graphically lower as well. This area is about 40 miles wide in the Park area and extends northward toward the Davis Mountains and southward into Mexico. Udden (1907a, pp. 80–81) termed this structural feature the Sunken Block. While the Sunken Block is a broad structural unit, sedimentary rocks within it have been much deformed, especially near igneous masses.

Major structures within the Sunken Block include the Christmas and Mariscal Mountains, Sierra San Vicente, the Adobe Walls anticline, and the western sides of the Long Draw and Chalk Draw grabens, where Comanchean rocks have been uplifted and exposed. Folded Gulfian strata are exposed along the crest of the Cow Heaven anticline. Folding and intrusive activity have deformed rocks of Gulfian age at Tortuga and Maverick Mountains and Gulfian rocks at McKinney and Grapevine Hills. The Chisos Mountains, near the geographic center of the Sunken Block, are capped by Upper Eocene-Oligocene lavas and are flanked by deformed Gulfian and Upper Eocene strata. Both the sedimentary rocks and lavas have been further deformed by intrusion of igneous rocks. Faults have broken all rocks in the Sunken Block area with the possible exception of Pleistocene and Recent deposits.

EASTERN BOUNDARY

Sierra del Carmen.—The Sierra Madre Oriental in Mexico is a series of discontinuous folds and fault-block ridges that extends northwestward across the Mexican States of Nuevo Leon and Coahuila and enters Texas east of Boquillas in Big Bend National Park. This mountain belt borders the eastern side of the Coahuila Platform. It generally coincides with Humphrey's (1956, pp. 26 and 31) Coahuila Ridge and Basin Province, and Murray et al. (1959, p. A2 and Pl. 1A) referred to these structures as the Coahuilian Marginal Fold Belt (Pl. XI). The belt is formed of isolated, generally northwesterly aligned, double-plunging anticlines or domes that are separated by broad, synclinal valleys, many of which contain bolson deposits. The northwest part of this province includes the ranges of the Sierra del Carmen and the Santiago and Del Norte Mountains that in Texas form the eastern Cordilleran Front.

The Sierra del Carmen reaches its maximum structural and topographic altitude in Coahuila, Mexico, only a few miles south of the Rio Grande. It is a broad uplift that narrows toward the north-northwest and dies out about 30 miles north of the Rio Grande. The Sierra del Carmen in Mexico is flanked on the east by the Serrania del Burro, an elongate northwest-trending uplift, and on the west by Sierra San Vicente and Mariscal Mountain, two faulted anticlinal uplifts that are prominent in Mexico but die out less than 10 miles north of the Rio Grande.

In Texas, the Sierra del Carmen is grossly a west-dipping monocline, broken into blocks by a series of normal faults, most of which trend northerly or northwesterly (Pl. III, especially parts of sections A-A′, B-B′, D-D′, and I-I′). Sierra del Caballo Muerto, on which Stuarts Peak (Pl. II; T, 25) and Sue Peaks (Pl. II; Q, 26) are prominent, is the backbone ridge of the Sierra del Carmen in Texas. The westernmost ridge is Cuesta Carlota (Pl. II; J–M, 25–26), and the highland belt from Stairway Mountain to Sierra Larga (off map) is the eastern boundary. Conspicuous valleys or deep canyons lie between most of the fault blocks. One of these is Ernst Valley (Pl. II; K–M, 25–26), which is in part a faulted syncline. The Strawhouse Trail (Pl. II; K, 26–27), Arroyo Venado (Pl. II; L–M, 28), and Margaret Basin (off map) occupy prominent valleys between fault blocks. Only the east-flowing Rio Grande and part of Heath Creek (Pl. II; O–P, 25–29) (locally called Telephone Canyon) flow through and across the mountain uplift.

The most diverse structures in the Sierra del Carmen of Texas are along the western margin near the Sunken Block. Here, anticlines, synclines, and small faults form a



Fig. 127. Looking southeast across fault blocks in the Sierra del Carmen. A, Sierra del Carmen in Mexico. B, Approximate location of the Boquillas mine. C, Sierra del Terminal, an east-dipping block of Comanchean limestone. D, Steeply dipping beds about 1 mile below the head of Boquillas Canyon pass northwestward into a normal fault.

belt between the west-dipping monocline in the Sierra del Carmen and the eastern side of the Sunken Block. Northwestward from near the head of Boquillas Canyon (Pl. II; J, 28), the strata dip eastward in contrast to the west-dipping monocline farther east (fig. 127). At the head of the canyon are two faults downthrown on the Comanchean rocks toward the east. Both faults extend southward into Mexico where the displacement increases. For 2 to 3 miles southward along the Rio Grande from the head of Boquillas Canyon are several en échelon east-dipping fault blocks (fig. 128). About 2 miles north of the head of Boquillas Canyon is a small graben (Pl. II; K, 27–28) with rocks of the Boquillas Formation exposed over most of the surface. Extending northwestward from it are three small grabens, all cut by faults. About 15 miles northwest of the river is a group of faults that extend from the Sierra del Carmen of Texas northwestward into the McKinney Hills (Pl. II; N–Q, 22–24) where they cut Gulfian rocks and intrusions. Within this group lies Alto Relex (Pl. II; N–O, 22–25), the west-facing escarpment of a horst. The fault marking the western boundary of the horst is downthrown to the west and is subparallel to faults near Muskhog Spring (Pl. II; Q–S, 22–24) that are also downthrown toward the west (fig. 129). The northwestern end of the Muskhog Spring faults is en échelon with the southeastern end of the Chalk Draw fault but is downthrown in the opposite direction (Pl. XI).

The largest faults in the Sierra del Carmen of Texas trend northwest; near their center and along their eastern margin the faults outline large blocks of westerly-dipping Comanchean limestone. The faults are followed by high steep escarpments in the limestone but some of the fault sur-



FIG. 128. Looking southeast toward the Sierra del Carmen escarpment in Mexico. Note the enéchelon arrangement and plunging ends of easterly tilted fault blocks.



FIG. 129. Looking north at the faults near Muskhog Spring (Pl. II; S, 22). Pen Formation (on left) is downdropped against flagstone in the Boquillas Formation (right).

faces are covered; where exposed the faults dip toward the downthrown side and are normal. Although faults are common throughout the Sierra del Carmen on both sides of the Rio Grande, near the river itself there is a tendency for the larger faults to bifurcate and decrease in magnitude so that the river crosses the uplift in a structural saddle. However, near Marufo Vega (Pl. II; L–M, 28) the Rio Grande crosses a fault block near its maximum vertical displacement; this fault block might have been raised later, perhaps by renewed movement. For a few miles north of the river most of the large faults increase in displacement, then diminish and/or die out near where Heath Creek crosses the Sierra del Caballo Muerto. North of Heath Creek, chiefly east of Big Bend National Park, the Sierra del Carmen is again broken by northwest-trending faults whose maximum displacement is near the latitude of Stuarts Peak (Pl. II; T, 25); these die out near the northern terminus of the Sierra del Carmen in Texas.

Dagger Mountain (Pl. II; N–Q, 3–4), a whale-back dome about 2 miles south of Dog Canyon, may be due to igneous intrusion. The mountain sides are steep, the Santa Elena Limestone emerges at the crest, and most of the structure is flanked by Gulfian formations. The mountain is bounded on the east by a normal fault downthrown toward the east, part of the southwest side is also faulted, and there are numerous small faults around much of the rest of the structure. Dagger Flat (Pl. II; O–P, 4) adjoins Dagger Mountain on the east and is a graben that separates the mountain from the Sierra del Caballo farther east. The west-dipping strata in the Sierra del Caballo Muerto are stepped down beneath the surface at the south end of Dagger Flat; at the north end strata likewise dip westward from the southern Santiago Mountains. The floor of the gra-

ben is a synclinal valley but it is broken by numerous faults that cause abrupt changes in the dip and strike of the beds.

The larger folds in the Sierra del Carmen of Texas trend northwest parallel to the faults. Baker (1928, p. 372) concluded that the faulting accompanied the folding and regional uplift. In Big Bend National Park, the parallelism between folds and faults is not perfect (Pl. II); some folds are clearly cut or offset by faults. P. B. King (1935, pp. 251–252) has shown similar relations in the Marathon region. In Big Bend National Park, the prominent northwest-trending axis of the Sierra del Carmen crosses minor northeast-trending folds, most of which are either broken, displaced, or largely obliterated by the northwest-trending faults. The most prominent northeast-trending arch is near Sue Peaks (Pl. II; Q, 26) where most of the larger faults in the Park diminished or died out. East of the Park several large faults cut directly across the arch.

Near Black Gap, east of Big Bend National Park (Pl. I), Tertiary lavas are folded and faulted (D.C.O. Wilson, 1951, p. 75) and rest unconformably on mid-Gulfian to Comanchean formations. According to Shambaugh (1951, pp. 39, 41, and map) the lava dips as steeply as 50° in the Black Gap syncline and in places is cut by normal faults.

In Mexico the Sierra del Carmen is bordered on the southwest by a high escarpment interpreted by Baker (1928, p. 358) as a high-angle reverse fault. Near the Rio Grande the northwest end of the fault passes northwestward into an overturned anticline (fig. 130); southeastward it dies out near the latitude of the Boquillas (Puerto Rico) mine. Farther southeast the western escarpment of the Sierra del Carmen in Mexico is bordered by a normal fault (fig. 131). The massive Comanchean limestone in the high Sierra del Carmen es-

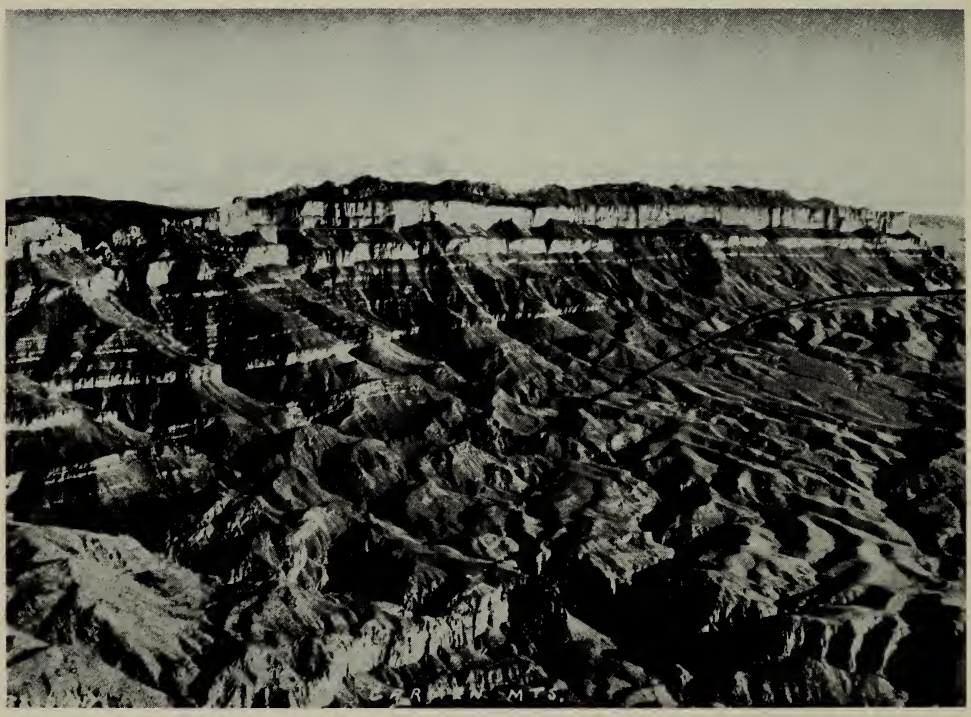


Fig. 130. The west-facing Sierra del Carmen escarpment in Mexico, showing the approximate location of a reverse fault that dies out in the vicinity of the Rio Grande. The jagged skyline is the Sierra Fronteriza, behind the Sierra del Carmen range.



FIG. 131. The southern end of the Sierra del Carmen escarpment, Coahuila, Mexico, showing plunge of the anticline toward the south.

carpment in Mexico rests on basal clastics about 240 feet thick. These and the lower part of the overlying limestone have been arched into a northwest-trending double-plunging anticline. At the highest part of the escarpment pre-Cretaceous metamorphic rocks emerge from beneath the basal clastics (Flawn and Maxwell, 1958). The conglomerate dips steeply to vertical away from the fault and is even slightly overturned in places. West of the Sierra del Carmen escarpment in Mexico is a shallow syncline, west of which is the ridge of Sierra del Terminal (Pl. XI), and beyond is a normal fault that forms the escarpment at the head of Boquillas Canyon (figs. 7, 127).

Volcanic rocks seem to be absent in the higher parts of the Sierra del Carmen in Mexico but are preserved in a few places along the eastern flank. The Sierra Fronteriza (Pl. XI), a tilted block of Comanchean limestone farther southeast, is cut by several intrusions and capped by several hundred feet of Tertiary lava and tuff.

Santiago Mountains.—Only the southern end of the Santiago Mountains is in Big Bend National Park (Pl. I). They are an anticlinal uplift, overturned toward the southwest, and broken by one or more thrust faults and several normal faults. There are two ages of thrust faulting followed by the normal faulting. The oldest faults are late Paleozoic thrusts in the Tesnus and older rocks. The youngest thrust faults are post-Cretaceous (Laramide) and displaced both Paleozoic and Mesozoic rocks. The normal faults cut the older structures and commonly cut and offset the thrust slices. Normal faults, largely concealed by alluvium, border a considerable part of the uplift on both sides of the range (Pl. III). The normal faults in the Persimmon Gap—Dog Canyon are younger than the youngest thrusts and are probably contemporaneous with faults in the Sierra del Carmen where some faults cut Tertiary lava.

The major thrust faults dip east and in some places they displace Paleozoic and

Comanchean formations westward over younger Cretaceous rocks. The southern end of the Santiago range is a narrow, sharp, overturned anticline with thrust faults along its western margin, ending about 4 miles south of Dog Canyon. Here the thrust plane passes into an overturned anticline that is cut by a normal fault at the northern end of the Sierra del Caballo Muerto. Erosion has breached the crest of the fold at Persimmon Gap, where the Tesnus (Mississippian and Pennsylvanian) was thrust westward over the San Vicente (Upper Cretaceous) and the Maravillas (Ordovician) crosscuts the Glen Rose (Lower Cretaceous) (Pl. IV).

Large normal faults occur in the Santiago Mountains, most of which are downthrown toward the east, like those in the Sierra del Carmen. Because of the faults and erosion, the highest part of the ridge does not always coincide with the structural crest of the fold. The asymmetry is beautifully shown three-quarters of a mile southeast of Persimmon Gap (fig. 132; Pls. VI, V) as well as at Dog Canyon (fig. 133; Pls. IV, V), about 5 miles southeast of Persimmon Gap.

In the Persimmon Gap area the thrust faults are of two ages. The older, late Paleozoic and pre-Cretaceous in age, involved Paleozoic rocks of the Ouachita structural belt including the Maravillas, Caballos, and Tesnus Formations. The thrust slices moved from southeast to northwest and the movement was of sufficient magnitude to bring the Maravillas over Tesnus. Such a fault occurs in the northwest face of the black Maravillas hill (Pl. II; S, 1) immediately southeast of Persimmon Gap. Similar structures occur below the crest of the fold about half a mile farther southeast.

The younger southwest-directed thrust faults displaced both Paleozoic and Cretaceous rocks and cut the older thrust slices approximately at right angles. This relationship occurs along the southeast flank of



Fig. 132. Thrust faults and complex folds, Persimmon Gap area. 1, Maravillas. 2, Tesnus. 3, Glen Rose. 4, Pen and alluvium.


E
D
E
C

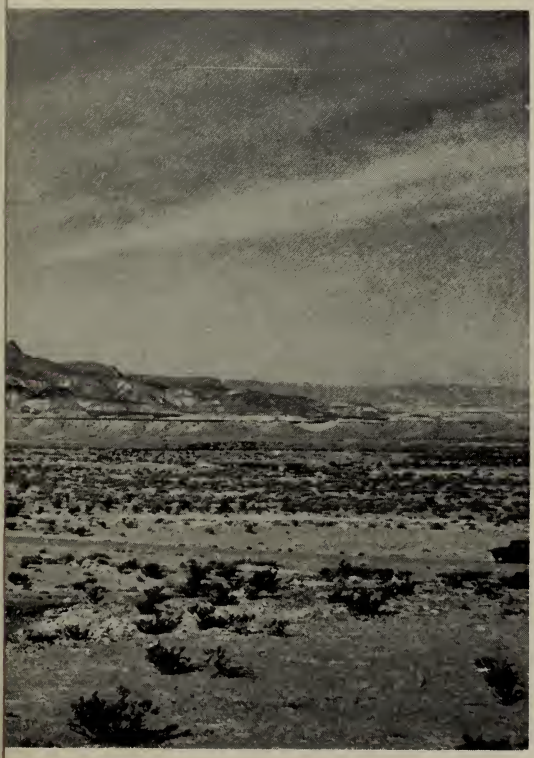




FIG. 133. Overturned fold and thrust faults at Dog Canyon. A, Glen Rose. B, Santa Elena. C, Del Rio. D, Buda. E, Boquillas. F, Overturned fold. G, Thrust faults.



FIG. 135. Terlingua fault escarpment at mouth of Santa Elena Canyon from about 5 miles distance; Mesa de Anguila (Texas) on right; Sierra Ponce (Mexico) on left.

the black Maravillas hill mentioned above, where Glen Rose is thrust onto Paleozoic rocks (Maravillas, Caballos, and Tesnus Formations). Along the west side of the gap, the same Paleozoic formations overrode the Glen Rose in one block and Pen in another, and Glen Rose overrode San Vicente, Pen, and Aguja in a third.

Farther southeast, Paleozoic rocks as parts of a thrust slice are exposed in seven more places. In one of these, probably Marathon or Alsate is thrust over Comanchean rocks (Glen Rose, Del Carmen, Sue Peaks, and Santa Elena). In another, Maravillas overrode Glen Rose and Sue Peaks. There are also thrust slices that involved only the Cretaceous rocks. These include Santa Elena strata thrust upon Glen Rose; Glen Rose on Santa Elena, San Vicente, Pen, and Aguja; lower Del Carmen on upper Del Carmen, Del Rio, and Aguja. Santa Elena slices overrode Del Rio, Buda, and Boquillas; San Vicente overrode Santa Elena; and San Vicente was thrust upon Pen. About 2,000 feet northeast of the Persimmon Gap benchmark (elev. 2,971 feet) is a small fenster wherein Maravillas is exposed below Glen Rose. Erosion has also exposed basal Tesnus along the front of a slice three-quarters of a mile south of the Persimmon Gap benchmark.

In Dog Canyon, Comanchean strata are nearly vertical and are in part overturned toward the northeast (fig. 134). Rocks near the middle of the canyon are sheared but there is no clear-cut surface of movement. Probably the thrust which generally follows the crest of the recumbent fold lies in the shear zone near the middle of the canyon.

Normal faults in the southern end of the Santiago Mountains flank the highest part of the uplift on both sides. One downthrows the Glen Rose northeastward against a long strip of Tesnus (Pl. IV). Just below the mouth of Dog Canyon a second large normal fault (covered on Pl. IV) downthrows Gulfian rocks, mostly San Vicente, eastward to the base of the range. Farther southeast (Pl. II), a normal fault, probably the same as that at the mouth of Dog Canyon, drops Boquillas against Glen Rose. This fault is related to the faults in the Sierra del Carmen of Texas which extend for a considerable distance along the eastern side of the Sierra del Caballo Muerto. The principal thrust in the southern Santiago Mountains passes southeastward into an overturned anticline that is cut by the normal fault on the west side of the Sierra del Caballo Muerto. In the foothill belt on the southwestern side of the Santiago range, a normal fault (much of it covered) downthrows Aguja against Glen Rose.

WESTERN BOUNDARY

Mesa de Anguila.—Mesa de Anguila and Sierra Ponce, the Mexico end of the mesa, are a high fault block on the western border of the Park (Pl. II; G–K, 1–6) that forms the western boundary of the Sunken Block. The Rio Grande has cut Santa Elena Canyon, a diagonal trench, across the mesa. The canyon deepens rapidly downstream, ending in the lowlands at the mouth of Terlingua Creek (Pl. II; G, 6), just above which it is 1,515 feet deep (fig. 5).

The Mesa de Anguila—Sierra Ponce uplift is bounded on its northeastern side by the Terlingua fault (Pl. II; G–K, 4–6), a normal fault downthrown eastward (Pl. III, sec. D–D′). The fault trace is marked by a high east-facing escarpment in Comanchean limestone (fig. 135). At the mouth of the canyon and also at one place a mile farther south, the massive Comanchean limestone beds have been flexed steeply downward by the drag of the downthrown side along the fault trace (fig. 136). Marl, clay, and flagstone of the Gulfian rocks on the downthrown side have yielded to erosion leaving an escarpment formed by hard, massive Comanchean limestone. The Terlingua fault is not a single fracture but a fault zone, and probably movement occurred along the zone at different times. The fault zone is traceable northwestward to near Comanche Spring (Pl. II; L, 4, off map); Yates and Thompson (1959, p. 39)

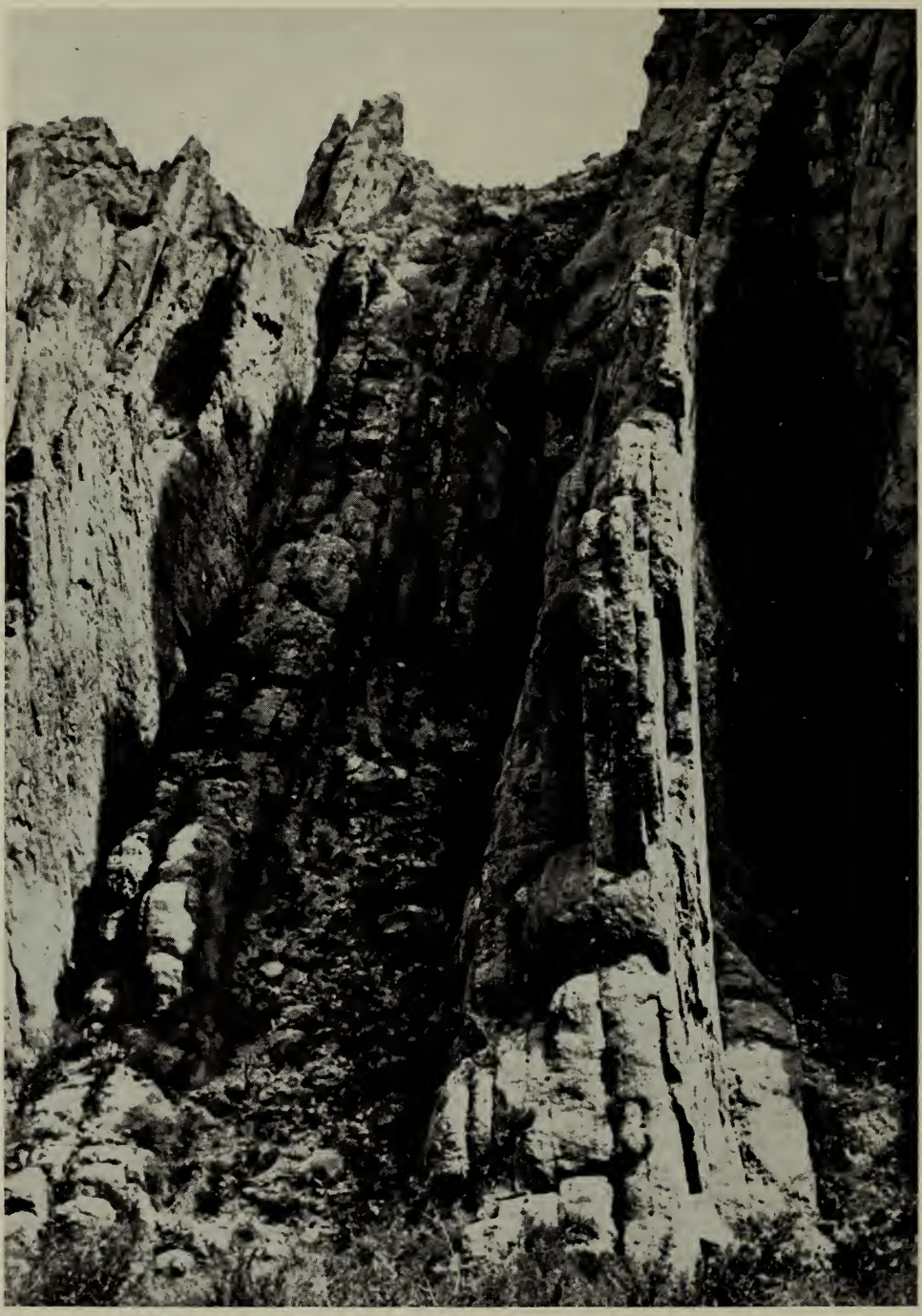


Fig. 134. Vertical Comanchean limestone beds in Dog Canyon.

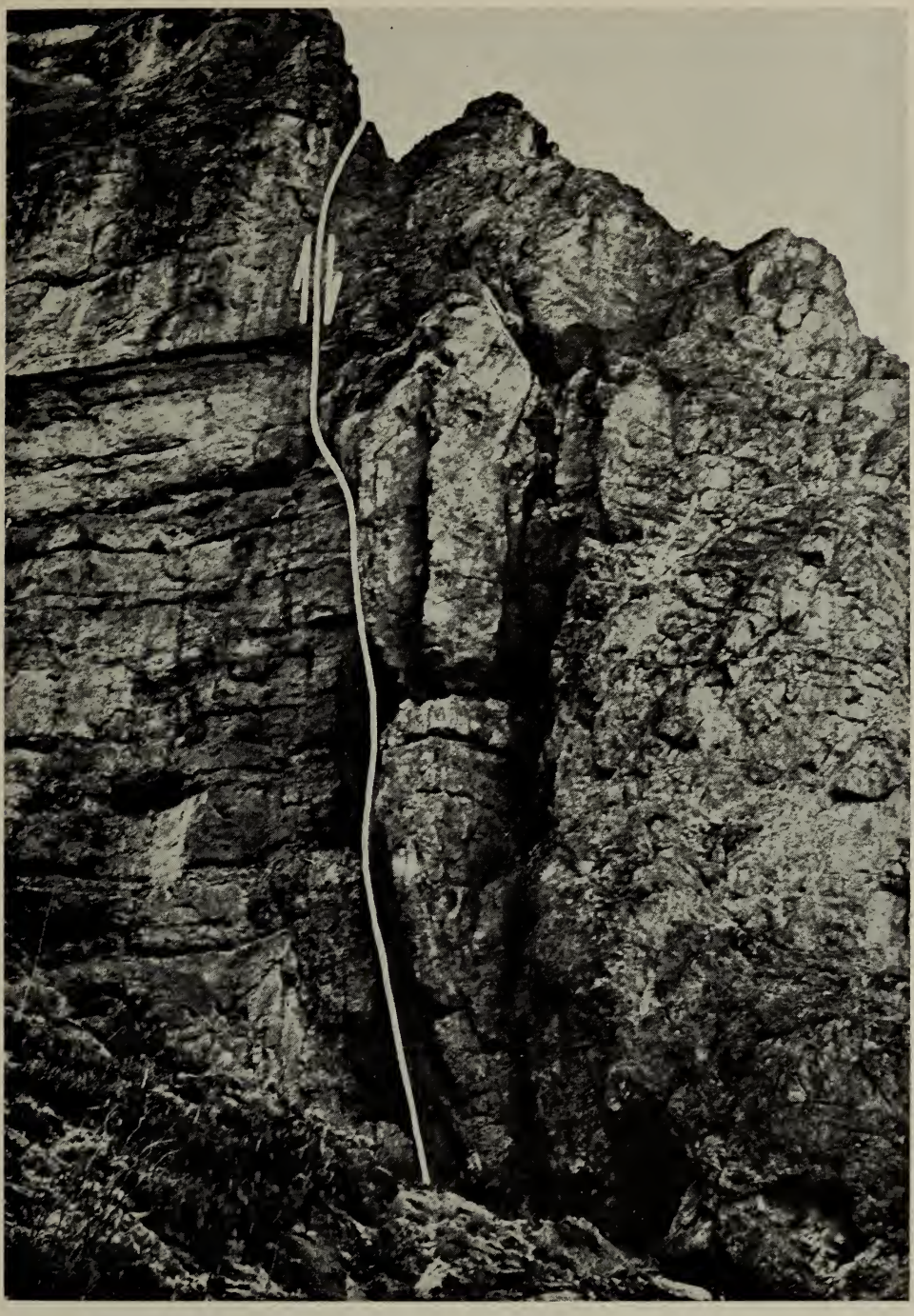


Fig. 136. The Terlingua fault. Drag in massive Comanchean limestone on right.

observed that the northwest-trending faults and perhaps the minor folds south and southwest of Tres Cuevas Mountain, 3 miles north of Comanche Spring, form the end of the Terlingua fault zone in that direction. The fault zone and the limestone escarpment behind it also extend 20 miles southeastward into Mexico beyond the Rio Grande.

The Terlingua fault at the mouth of Santa Elena Canyon (Pl. II; H, 6) has about 2,900 feet of displacement. On the downthrown side, the San Vicente Member of the Boquillas Formation lies against Comanchean limestone, probably Glen Rose. The fault escarpment is a sheer wall (1,515 feet high) whose rim is little indented. Vertical beds resulting from drag are attached to the fault surface at the mouth of the canyon and in other places (fig. 136), and some slickensided areas are preserved. The fault movement appears to be very young. Between 3¼ and 5½ miles north of the Rio Grande, the fault forming the high escarpment at the mouth of Santa Elena Canyon bifurcates and dies out (Pl. II; J, 4–5). Here another fault begins a short distance to the east-northeast of the major fracture and forms the base of the Mesa de Anguila scarp farther northwest. This segment of the fault zone extends northwestward, disappearing near Comanche Spring. In this segment of Mesa de Anguila, the escarpment is offset by a short cross-fault, and although slickensided surfaces have been preserved in some places, the escarpment is more eroded than at the mouth of Santa Elena Canyon and at several places has receded enough so that stock trails can ascend it.

A third fault zone begins west of where the fault at the mouth of Santa Elena Canyon begins to die out (Pl. II; J, 4–5). These faults trend slightly more westerly than the others and form a high inner escarpment extending northwestward to near Lajitas (Pl. II; L, 1, off map). The escarpment has been much eroded and is somewhat receded, suggesting that the faults northwest of the latitude of Sierra Aguja (Pl. II; K, 5) may be earlier than the fault at the mouth of Santa Elena Canyon.

Along the Terlingua fault zone in Mexico there are places where the displacement is greater than in Texas. South of Castolon, near where the San Carlos trail ascends the Sierra Ponce rim (Pl. II; D, 9, off map), basal Chisos Formation (Alamo Creek Basalt) is in contact with lower Del Carmen Limestone. Beginning about half a mile northeast of the escarpment is a sequence of Chisos Formation, extending from Alamo Creek Basalt through Bee Mountain Basalt, exposed on the downthrown side of the fault (fig. 137). Still farther northeast the Mule Ear and Tule Mountain Members are preserved. The presence of these units requires a displacement as much as 1,000 feet greater (3,900 feet) than at the mouth of Santa Elena Canyon. The displacement in Mexico was distributed through several fractures. The San Carlos trail on its ascent to the Sierra Ponce rim crosses complex folds and minor faults in Comanchean rocks on the upthrown side of the fault. Some of these relations may be seen in the upper left part of figure 137.

Mesa de Anguila, the block behind the Terlingua fault, is tilted southwestward at an average dip of about 10°. Most of its surface, especially its high northeastern rim, is a stripped surface on Comanchean limestone, but to the northwest the basal Boquillas Formation and a thick basaltic sill are present. These same units are preserved in fault blocks downthrown southwestward toward the Rio Grande (Pl. II); at the northwestern end of Mesa de Anguila, they form a horst between the Terlingua fault zone and faults along the Rio Grande. The individual faults are not traceable for long distances, but when one fault begins to die out another begins and the zone is traceable northwestward for 30 to 40 miles beyond Lajitas. Southwest of the Rio Grande, in Mexico, the faults in this belt are downthrown northeastward toward the river, and for about 20 miles northwest from near Lajitas, the Rio Grande courses



Fig. 137. Chisos beds, including the Bee Mountain Basalt, downthrown along the Terlingua fault in Mexico, south of Castolon, Texas. A, Del Carmen Limestone. B, Bee Mountain Basalt.

along the lowest part of a compound graben.

Several of the faults that extend northwestward from Mesa de Anguila displace the Chisos Formation from its basal Alamo Creek Basalt through the Tule Mountain Trachyandesite Member that caps Lajitas Mesa (Pl. II; L, 1, off map). On the southeastern slope of Santana Mesa, 11 miles northwest of Lajitas (Pl. I), the faults in this group displace the Tule Mountain Member (Upper Eocene), the Mitchell Mesa (Oligocene?), and about 1,000 feet of post-Mitchell Mesa volcanic rocks (Tascotal?). Still farther northwest they displace the Rawls Basalt (Oligocene or younger) as well as late Tertiary or Quaternary bolson deposits. The faults in this zone are not all the same age; some are older than the Tertiary volcanic rocks (Chisos Formation). On the Fresno Canyon road 2 miles east of Lajitas, a small block of San Vicente Member and Pen Formation are covered by the virtually flat-lying Alamo Creek Basalt on the southeast slope of Lajitas Mesa (fig. 138). This block and faults in the Terlingua uplift are of the same age, are related to the Laramide orogeny, and probably are correlative with some of the faults in the Santiago—Sierra del Carmen.

Terlingua uplift.—The Terlingua uplift, including the Terlingua monocline to the southeast and the Solitario farther northwest, was first elevated during the Laramide orogeny. These two features constitute a structurally high unit about 18 miles long and 6 to 10 miles wide. The Terlingua uplift with Mesa de Anguila forms the western border of the Sunken Block in the Big Bend area of Texas. Domes and grabens are the dominant structures through the area of the larger Terlingua uplift, but small intrusions cause many irregularities in the dip of the beds, many beds are tilted or offset by innumerable faults, and in some places solution of the limestone has caused collapse which extended upward into the



FIG. 138. Lajitas Mesa from the south showing highly deformed ridge of Cretaceous rocks covered by gently dipping Tertiary volcanic rocks. A, San Vicente Member. B, Pen Formation. C, Alamo Creek Basalt. D, Tule Mountain Trachyandesite.

overlying rocks and formed the breccia pipes of the Terlingua district. Yates and Thompson (1959) described the area in detail.

Most of the faults in the Terlingua uplift are normal and a majority of them are close to the borders of the larger structure. Several of the largest faults form the boundary along grabens within the larger uplifted area; some of these are fault zones rather than single fractures. Yates and Thompson (1959, p. 39) reported that the deposition of calcite veins in many of the faults showed good evidence of repeated movement. Thrust faults are not common in the Terlingua monocline but they do occur in the Cretaceous rocks in some places. These are: (1) about a mile north of Lajitas Mesa; (2) along the southeast flank of Reed Plateau, ½ mile west of Terlingua; (3) 1½ miles west of the Reed Plateau (this one is offset by a normal fault); and (4) a mile south of Cigar Mountain (Pl. I). Numerous small thrust faults occur in both the Cretaceous and Tertiary volcanic rocks along Fresno Creek west and southwest of the Solitario. In one place the Buda is thrust over the Boquillas (fig. 139); in another a small thrust in the San Vicente Member was eroded and covered by Chisos Formation (fig. 140); and at a third, multiple thrusting repeated the Mule Ear Spring Member of the Chisos Formation (fig. 141). Associated with many of the small thrust faults is complex folding in the weaker rock layers (fig. 142).

The Tertiary volcanic rocks overlap the folded Cretaceous formations and lie on Paleozoic rock at a few places inside the rim of the Solitario. They also rest on Cretaceous rocks at a few places, mostly in grabens, on the Terlingua monocline. No Tertiary rocks occur on top of Mesa de Anguila or Sierra Ponce, but they are preserved in downfaulted areas to the west and north. The Tule Mountain Trachyandesite,



Fig. 139. Buda Limestone thrust over weaker Boquillas beds (San Vicente?) on west side of Fresno Canyon road, west of the Solitario. A, Thrust plane. B, Boquillas Formation. C, Buda Limestone.

which is the most extensive lava in the Chisos Formation, lies at altitudes of 5,000 to 5,500 feet on the northwest side of the Chisos Mountains. It is downfaulted to 3,200 feet at Sierra Aguja, which is only 600 feet lower than the highest point on Mesa de Anguila. It seems likely that at least the upper Chisos Formation once covered Mesa de Anguila and that most members in the Chisos Mountains were continuous with present outcrops in the Bofecillos Mountains, covering all of the pre-Tertiary folding and faulting in the Terlingua uplift.

THE SUNKEN BLOCK

Between Mesa de Anguila and the Terlingua uplift at the west, and the Sierra del Carmen and Santiago Mountains 40 miles to the east, is a structurally low area, the Sunken Block of Udden (1907a, pp. 80–81). The part of the Sunken Block described in this report is bordered on the south by the Rio Grande and ends 35 to 40 miles north of that river in the uplifts of the Christmas and Rosillos Mountains and the Corazones Peaks; the area is the central part of Big Bend National Park. The dominant structures in the Sunken Block trend northwest, parallel to the principal Laramide alignments (Pl. XI). Most of the northwest-trending folds were formed during the Laramide orogeny and most of the normal faults are of post-Upper Eocene age. The principal pre-Eocene deformation resulted in a group of folds formed along a northwest-trending axis that extended northwestward from Mariscal Mountain at the southernmost southward bend of the Rio Grande to the Christmas Mountains. The deformation that formed the high Chisos Mountains peaks near the center of the Sunken Block modified the folds of the Laramide deformation; these high peaks of the Chisos Mountains are eroded Tertiary extrusive rock, raised by post-Upper Eocene and post-Oligocene doming. The



Fig. 140. Small thrust fault in San Vicente beds, near U. S. Geological Survey benchmark R-749 in Fresno Creek, southwest of the Solitario.

A, Thrust plane in San Vicente beds. B, San Vicente beds. C, Post-San Vicente erosion surface. D, Channel filled by Tertiary volcanic rocks (Duff). E, Mule Ear Spring Tuff. F, Tule Mountain Trachyandesite.

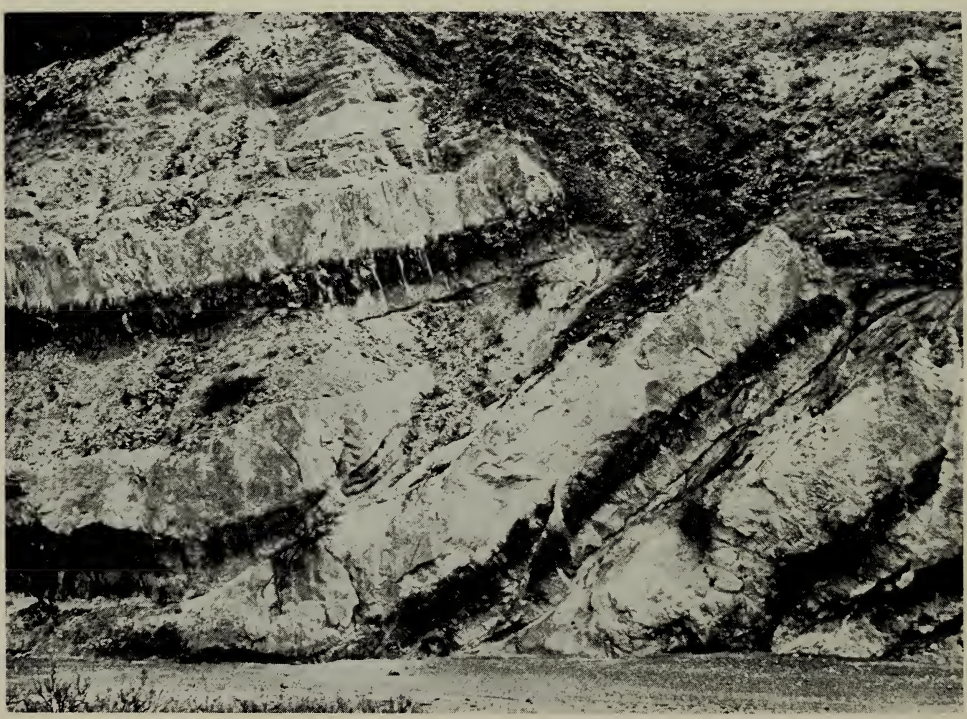


Fig. 141. Multiple thrust faults cutting Mule Ear Spring Tuff (dark layer) in bank of Fresno Creek southwest of the Solitario.



FIG. 142. Complex folding in Boquillas along Fresno Creek, northwest of the Solitario.

normal faults southwest of the Chisos Mountains are post-Upper Eocene age. Erosion throughout the Chisos Mountains has stripped the Tertiary volcanic rock cover in some places, exposing the older post-Cretaceous folds, faults, and igneous intrusions.

FOLDS AND STRUCTURES CAUSED BY, OR MODIFIED BY, INTRUSIONS

Mariscal Mountain.—Mariscal Mountain, at the southernmost part of the big bend in the Rio Grande (Pl. II; A–F, 19–22), is a narrow asymmetric anticlinal ridge modified by faults, in which the Santa Elena Limestone is exposed along most of the crest of the ridge (fig. 143). The Rio Grande crosses the mountain in Mariscal Canyon, which is excavated to a depth of about 1,650 feet. The abandoned Mariscal mine is at the crest of the fold near its northern end, and from there the anticline plunges rapidly. South of the mine the uplift rises and widens across the river into Mexico where it coalesces with Sierra San Vicente toward the east.

West of the crest of the fold, the strata are nearly vertical, or even overturned, highly brecciated in part, and cut by a thrust fault. Farther west there are several normal faults, downthrown toward the west. The dips on the east limb are more gentle, but here the rocks are broken by normal faults, most of which are downthrown toward the east. About 4 miles north of the Rio Grande the sharp asymmetric folding flattens, the thrust fault dies out, there are several normal faults and minor folds, and the uplifted area changes from a sharp asymmetric anticline to a broad arch broken by normal faults, most of them tilted toward the east.

Some of the normal faults just north of the Rio Grande extend southward across the river into Mexico where they increase in magnitude of displacement. One of these, beginning near the south end of the sharp asymmetric fold, extends southward



Fig. 143. View looking southeast across folded ridges and block fault mountains in Big Bend National Park and adjacent parts of Mexico.

A, Cow Heaven anticline, crest is covered. B, Mariscal Mountain. C, Sierra San Vicente. D, Rio Grande. E, Sierra del Carmen, Mexico. F, Sierra Fronteriza, Mexico.

along the crest of the range against a narrow strip of down-dropped Boquillas Formation. This structure forms a conspicuous valley, several miles long in Mexico, Mariscal Mountain is separated from the San Vicente uplift by the Solis Graben (Pl. II; C–E, 22–23), which is 1½ miles wide near the Rio Grande with vertical displacement of about 2,000 feet and is floored by the Boquillas and Pen Formations. The graben dies out northward in the area southeast of Talley Mountain (Pl. II; E–F, 22), but southward into Mexico, it passes into a syncline between the Mariscal Mountain and Sierra San Vicente uplifts.

Along the foothills west of Mariscal Mountain in Texas the Gulfian rocks are upturned into conspicuous hogbacks and are much faulted. The Pen Formation is abnormally thickened in places, apparently by faulting, but the faults are difficult to recognize because of the soft shale. Most faults parallel the axis of the anticline, are downthrown toward the west, and at least one of them extends into Mexico where it borders a low west-facing escarpment of Comanchean limestone. A massive, basaltic, tabular intrusion, with low-angle cross-cutting relations, lies in the Pen Formation near the Rio Grande (Pl. II; A–B, 20); it transgresses the Pen Formation northward, intrudes basal Aguja near the latitude of the Mariscal mine, and extends around the north end of the Mariscal anticline to disappear in the Aguja Formation southeast of Talley Mountain. The sill-like body was folded concordantly with most of the sediments and is younger than the Aguja Formation but older than the Laramide deformation.

Sierra San Vicente.—Sierra San Vicente (Pl. II; D–E, 23–24) lies east of Mariscal

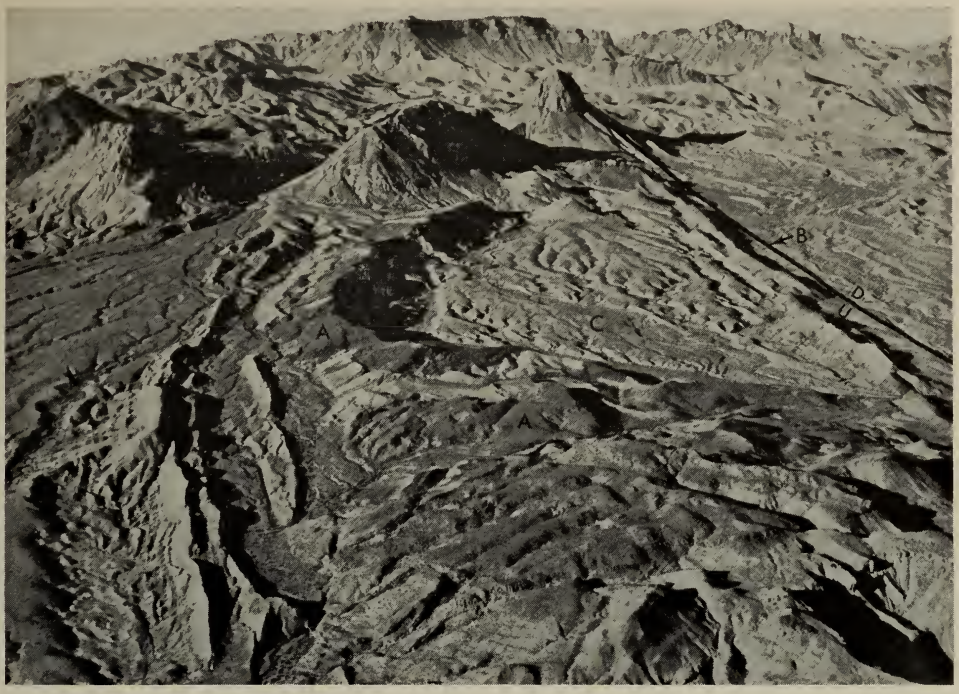


Fig. 144. The northern half of the Cow Heaven anticline looking toward Elephant Tusk and the South Rim of the Chisos Mountains. The flank of Cow Heaven Mountain is in the lower right. A, The dark band is a sill which swings around the fold and caps hogbacks right center. B, The Cow Heaven fault is right center; Chisos Formation overlies Aguja on the northern end of the anticline. C, Pen Formation exposed in crest of the fold.

Mountain but only the northern end of the fold is in Texas. Like Mariscal Mountain, it is an asymmetric anticline exposing the Santa Elena Limestone along its crest; it also is flanked by Gulfian formations and increases in both topographic and structural elevation southward in Mexico. Unlike Mariscal Mountain, the crest of the fold is on the east side of the ridge and the Rio Grande flows around its northern plunging end without cutting a deep canyon.

For half a mile north of the river there is a fault on the east side of the crest of the range, and a similar fault appears in about the same position 2½ miles toward the north; both are downthrown toward the east and are probably normal. Near the Rio Grande the rocks on the east side of the fold dip steeply eastward and are vertical in Mexico a few miles farther south. Possibly thrust faults occur along the crest of the fold in Mexico, and the San Vicente fold probably had the same history as the Mariscal Mountain uplift.

Cow Heaven anticline.—The Cow Heaven anticline (Pl. II; C–G, 17–19), northwest of Mariscal Mountain, is a low fold about 8 miles long and 2 miles wide (fig. 144). Cow Heaven Mountain, the highest part of the anticline, has a rounded crest formed on the surface of a sill. Elsewhere the sill has been breached; it forms hogbacks on the flanks of the structure. The less resistant Aguja and Pen Formations are carved into a topographic trough along the crest of the fold. The sill resembles the tabular intrusion on the west side of Mariscal Mountain, and it too was emplaced in the Aguja Formation and folded concordantly in the anticline. At the north end of the anticline there was sufficient post-Gulfian erosion to remove the Javelina

and upper half of the Aguja Formation before the Chisos Formation (Upper Eocene) was deposited. South of the gravel-covered end of the Cow Heaven anticline are several small folds and a complex of fault blocks, all partly covered (Pl. II; A–C, 19–20). These features apparently continue southward beneath the alluvium in the Rio Grande valley to join Mariscal Mountain in Mexico.

Chisos Mountains.—The Chisos Mountains (Pl. II; E–N, 15–19) lie in the geographic center of the Sunken Block and are the highest topographic feature in the Park. They are an oval-shaped feature, about 10 to 15 miles across, in which intrusive doming and block faulting are the most conspicuous features (Pl. III, secs. C–C′, D–D′). The principal intrusions are probably all cupolas, joined at depth to a larger pluton. The intrusions followed and rejuvenated an axis of Laramide deformation extending from Mariscal Mountain along the Cow Heaven anticline northwestward to the Christmas Mountains. Laramide structures not obliterated by the intrusive doming are preserved in the Basin (Pl. II; L, 15–16) and at Tortuga Mountain (Pl. II; H–J, 17).

The most prominent major feature, and probably the youngest in the Chisos Mountains, is the pluton that forms a crescent-shaped mass extending from Ward Mountain (Pl. II; K–L, 14–15) past Vernon Bailey Peak (Pl. II; M, 15) and Pulliam Peak (Pl. II; M, 15–16) to several more or less isolated bodies east of Green Gulch (Pl. II; L–M, 17). Most of its exposed parts formed steep mountains and deformed the adjacent formations during emplacement. The Basin (Pl. II; L, 15–16) is encircled by the pluton on the west and north and is an eroded syncline of Gulfian and Tertiary rocks (fig. 11). The Ward Mountain part of the intrusion strongly deformed Cretaceous rocks on the west side of the Basin and elevated the Boquillas Formation 2,000 to 3,000 feet above its normal stratigraphic position. Boquillas strata are plastered to the sides of the intrusion; locally, they stand vertical and locally they are mineralized at the contact. At Laguna (Pl. II; K, 15), the Boquillas strata are plastered to the sides intrusion at angles as steep as 30°. Farther south the pluton intrudes the Chisos Formation (Pl. II; J, 15), which dips away at about 25°.

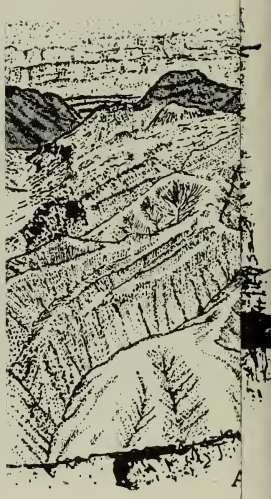
Southwest of Ward Mountain the intrusive contact is covered by talus. Farther out in front the Chisos Formation is folded, and beds nearest to the intrusion dip toward Ward Mountain at angles of 5° to 12° (Pl. II; K–L, 15). This suggests that the intrusion was emplaced from the southeast, and as it ascended, it crosscut, overrode, and crumpled the Chisos Formation beneath and dragged forward the elevated block of Cretaceous formations now exposed in the Basin.

Discordant relations of the pluton along the north flank of Vernon Bailey and most of Pulliam Peaks cannot be confirmed because heavy talus covers the lower slopes, but a quarter of a mile farther north the Chisos Formation appears to dip beneath the intrusion in much the same manner as that west of Ward Mountain. At some places, however, especially along the northeast flank of Pulliam Peak, west of Green Gulch (Pl. II; M, 17), the Chisos Formation ends against the intrusion. Farther southeast, east of Green Gulch at the extreme eastern end of the pluton (Pl. II; M, 17), the Chisos Formation dips away from the intrusion (fig. 145). In one arroyo vertical Chisos Formation is plastered to the side of the pluton, and farther south, between Casa Grande and Lost Mine Peaks (Pl. II; L, 17), it dips away from the intrusions at angles of 5° to 15°. The overlying South Rim Formation in the higher parts of the Chisos Mountains is domed by the pluton, but in most places dips are no steeper than 12°. The Burro Mesa Riebeckite Rhyolite Member is somewhat deformed next to the pluton, on the north side of Pulliam Peak (Pl. II; M, 16), and at Emory Peak (Pl. II; K, 16). Emplacement of the pluton was thus post-Oligocene or else intrusive activity was renewed as late as post-Oligocene time.



FIG. 146. Sketch from photographs of panoramic view from South Rim of the Chisos Mountains.

A, Near center of the South Rim. B, East end of South Rim. C, West end of South Rim. D, "Shot Tower" in the Mexico Sierra del Carmen. E, Sierra del Carmen escarpment (Mexico). F, Fronteriza Mountains (Mexico). G, Chilicotal Mountain. H, Talley Mountain. I, Sierra San Vicente. J, Mariscal Mountain. K, Sierra Ponce—Mesa de Anguila. L, Sierra Ponce escarpment (Mexico). M, Santa Elena Canyon. N, Mesa de Anguila escarpment. O, Tortuga Mountain. P, Elephant Tusk. Q, Backbone Ridge. R, Cow Heaven anticline. S, Dominguez Mountain. T, Punta de la Sierra. U, Sierra Quemada. V, Cerro Castellan. W, Trap Mountain. X, Bee Mountain. Y, Sierra Aguja.



146. Sketch from photogr

Rim. C, West end of So
Mountain. I, Sierra San
uga Mountain. P, Eleph
ountain. Y, Sierra Aguja.



FIG. 145. Eastern end of Chisos Mountains pluton, looking south from near road in Green Gulch. A, Approximate position of contact between intrusive and extrusive rocks. B, Rim of the intrusion. C, Deformed Chisos Formation, mostly covered. D, Domed lava units in the South Rim Formation.

Several domical intrusions and some dikes in the southern Chisos Mountains are probably related to the pluton and are of the same age. Among these are Sierra Quemada, Tortuga Mountain, Backbone Ridge, Elephant Tusk, and Hayes Ridge (fig. 146). The Tortuga Mountain (Pl. II; H–J, 16–17) and part of the Backbone Ridge (Pl. II; G, 17) intrusions are in contact with Aguja Formation; the others were emplaced in the Chisos Formation. At Tortuga Mountain and Backbone Ridge, the Cretaceous rocks were deformed and eroded prior to deposition of the Chisos Formation. At Backbone Ridge, on the northwest end of the Cow Heaven anticline, the Chisos Formation, at about the stratigraphic level of the Alamo Creek Basalt, lies directly on the upper marine part of the Aguja Formation. At Tortuga Mountain the crest of a dome was truncated, removing the Javelina and upper Aguja Formations before 200 feet of Canoe Formation was deposited, and the Canoe strata are overlain by Chisos Formation at a stratigraphic level above the Alamo Creek Basalt.

The deformation of Gulfian formations in the Basin (Pl. II; L, 15–16) of the Chisos Mountains was briefly mentioned on page 171. They were deformed and the Javelina and upper Aguja Formations eroded prior to deposition of the Chisos Formation. There was a second epoch of uplift and erosion prior to deposition of the South Rim Formation, and finally there was deformation of both Cretaceous and Tertiary formations by the emplacement of the Chisos Mountains Pluton.

Eastward from the nearly vertical dips in the Boquillas Formation, along the eastern flank of Ward Mountain, the dips in the Pen and lower Aguja Formations flatten to 35°. The Cretaceous formations are overlain by Chisos Formation at a stratigraphic level 425 feet below the Ash

Spring Basalt. The Alamo Creek Member is absent, and the maximum dip in the Chisos Formation is 18° where it overlies the erosion surface in the Aguja Formation. An erosion surface beneath the South Rim Formation truncates older formations from a stratigraphic level 40 feet above the Bee Mountain Basalt Member of the Chisos Formation down to about 200 feet below the top of the Pen Formation. Along the north side of the Basin, the contact between the pluton and the sedimentary formations is covered, but the character of beds in a nearby exposure of Aguja Formation suggests that the sedimentary rock units end abruptly against the intrusion. Faulting has not been observed and if present the fault is covered (Pl. II).

Chisos Pen anticline.—The Chisos Pen anticline (Pl. II; N–O, 12–13), 5 to 6 miles northwest of the Chisos Mountains, lies in the post-Cretaceous structural belt that extends from Mariscal Mountain northwestward to the Christmas Mountains. The fold involves the upper Boquillas (San Vicente Member), Pen, and Aguja Formations and four flanking sills, all in the Aguja (fig. 2). East and southeast of the main anticline are lower folds in the Aguja and Javelina Formations that are probably the same age. The Burro Mesa fault, downthrown toward the west, cuts diagonally across the Chisos Pen anticline and its southern end is buried beneath the Tertiary volcanic rocks that cap Burro Mesa. Erosion has stripped most of the resistant rocks from the crest of the anticline, and the Pen Formation underlies a broad valley at the north end of the fold.

Christmas Mountains.—The Christmas Mountains, an elliptical dome 4 to 5 miles across, are about 12 miles northwest of the Chisos Mountains. Only their southern flanks lie within the mapped area of this report (Pl. II; P–R, 12–13). The Comanchean Santa Elena Limestone forms the surface of much of the uplift, but tuff and volcanic flow breccia or agglomerate cap the highest peaks. The dome is flanked by Gulfian formations, which are invaded by several massive sills and are broken by normal faults downthrown toward the southwest (fig. 147). Some of the largest faults continue southeastward into the Park area.

According to Bloomer (1949a, pp. 34–35), an irregular mass of gabbro, a mile long and half a mile wide, is exposed along the southwest flank of the uplift, which is probably part of the laccolith that formed the dome. As the principal fault that flanks the uplift on the southwest ends near the gabbro, both the doming and faulting may have occurred at the time of intrusion. The dome is cut off abruptly at its northwest end by an east-west fault, on whose northern downthrown side volcanic tuff and agglomerate are preserved. Probably these deposits were originally continuous with the volcanic remnants on the summit of the dome.

Several folds occur in Cretaceous rock on both sides of the principal belt of Laramide deformation that extends northwestward from Mariscal Mountain to the Christmas Mountains. The principal folds are the San Vicente anticline, Lone Mountain anticline, and Maverick Mountain anticline.

San Vicente anticline.—The San Vicente anticline is 6 to 8 miles northwest of Sierra San Vicente (Pl. II; G–J, 23–24). It is about 5 miles long; its crest is formed by a narrow belt of Pen Formation with Aguja Formation on its flanks. The anticline was formed after Aguja time and the rocks were broken and offset by normal faults.

Lone Mountain anticline.—Northeast of the Chisos Mountains there appears to be an anticline in the Upper Cretaceous strata, but details cannot be worked out because of extensive alluvial cover. The highest peak is Lone Mountain (Pl. II; O, 19), which rises 500 to 600 feet above the gravel plain. It is formed of westerly dipping Aguja Formation which has been cut by a siliceous sill. The mountain is completely surrounded by alluvium and the contact relations between the Aguja and



FIG. 147. Looking northeast at the faulted face of the Christmas Mountains.

other formations are concealed. The Chisos Formation crops out three-fourths of a mile southwest of the Aguja exposed in Lone Mountain; there is not enough room for a normal sequence of Javelina Formation between the outcrops of Aguja and Chisos Formations. Presumably the Javelina Formation was removed by pre-Chisos Formation erosion as faults have not been found. The eastern limb of the anticline is preserved in Aguja Formation and a sill about a mile east of Lone Mountain. The crest of the fold is covered by alluvium. The southeast end of Lone Mountain anticline is preserved in the Aguja and a partial sequence of Javelina Formation immediately northeast of Nugent Mountain (Pl. II; L, 20). The northwestern end is formed by outcrops of the Boquillas and Pen Formations immediately southeast of Paint Gap Hills (Pl. II; Q, 17).

Maverick Mountain anticline.—Maverick Mountain (Pl. II; N, 9–10), 10 miles west-northwest of the Chisos Mountains, is a small boss intruding Boquillas, Pen, and Aguja Formations that were previously folded to form the Maverick Mountain anticline. Most of the intrusion is in contact with the Pen Formation but some remnants of the San Vicente Member of the Boquillas occur on the south, north, and northwest sides, and a small block of the Aguja Formation flanks the intrusion on the southwest. The strata dip steeply away from the intrusion near the contact but flatten rapidly farther out. The anticline is widest near the northwestern edge of the mapped area and narrows southeastward where it is much covered by alluvium. The San Vicente Member, Pen, Aguja, and Javelina Formations were folded and eroded prior to deposition of the Chisos Formation, which rests on the Javelina Formation in the limbs of the fold. Younger folding, probably along the same trend, deformed the Chisos Formation in the northwestern escarpment of Burro Mesa.

Several intrusive domes not clearly related to either the Laramide or Tertiary deformation occur in the Sunken Block.

The largest of these are the McKinney Hills, Grapevine Hills, and Glenn Springs laccoliths.

McKinney Hills.—The McKinney Hills, 9 to 10 miles northeast of the Chisos Mountains, are a rough, hilly, irregularly shaped, faulted area, probably of laccolithic origin (Pl. II; N–Q, 22–24). The igneous rocks emplaced in the Gulfian formations are mostly olivine microgranite, and the base of the intrusion on the east side of the laccolith is at a stratigraphic level near the middle of the Pen Formation. At three places on the west side of the uplift, blocks of San Vicente are on top of the intrusion, and on the north side of the Aguja is the upper contact formation. Aguja Formation lies on top of the intrusion in a northwest-trending belt across the middle of the area. These relations suggest either a "pine tree"-shaped laccolith or a mass that crosscut the Pen Formation carrying roof pendants of the San Vicente Member upward. Both the intrusion and the sedimentary rocks are repeated by normal faults. See Plate III, sections B–B′, D–D′, and J–J′.

Grapevine Hills.—The Grapevine Hills (Pl. II; P–Q, 19) are 7 miles northeast of the Chisos Mountains and west of the north end of the McKinney Hills. They are probably laccolithic but the floor of the laccolith is not exposed (Pl. III, sec. A–A′). Much of the top of the igneous rocks is covered but upper Aguja and lower Javelina Formations are preserved in places, dipping away from the uplift. The Canoe Formation, intruded by a rim sill, also dips away from the uplift on the south and east (fig. 9). The intrusion is more regular than the McKinney Hills, but here also both the sedimentary and intrusive rocks are broken by normal faults.

Glenn Springs laccolith.—The Glenn Springs laccolith, 5 miles southeast of the Chisos Mountains (Pl. II; H, 20), intrudes the Aguja Formation that dips away from the intrusion on all sides (fig. 148). The base of the laccolith is not exposed, but presumably emplacement was near the top of the Aguja for the Javelina Formation overlies the Aguja on all but the northwest side, where it is probably covered. The laccolith lies in a syncline in which a remnant of Black Peaks Formation (Paleocene) is preserved. Both the upper Gulfian and Paleocene formations were deformed by the emplacement. The intrusion is cut by one normal fault; dikes to the southwest seem to be related to the intrusion.

FAULTS IN THE SUNKEN BLOCK

The major faults in the Sunken Block trend northwest-southeast, closely parallel to the Mariscal–Christmas Mountains trend. Faults are rare in the high central Chisos Mountains but are numerous on all mountain flanks except the east, where they are probably present but covered. The faults cut all the rocks from the Comanchean through the South Rim Formation (Oligocene), and possibly the post-Oligocene valley fill deposits are broken in some places. They are most easily recognized where rocks of unequal hardness are thrown adjacent to each other on opposite sides of the fault trace, but in some soft rocks the color is a helpful distinguishing feature (fig. 149).

One thrust fault of Laramide age occurs on Mariscal Mountain. All other faults are normal and younger than the Mariscal Mountain thrust. There was more than one period of normal faulting and perhaps there was recurrent movement along some faults. West and southwest of the highest peaks in the Chisos Mountains are conspicuous fault block ridges capped by massive lavas. Some of these tilted blocks were extensively eroded during post-Chisos Formation time, producing fault-line scarps. Canyons were cut across some fault blocks before the youngest lavas were deposited, as indicated by the lava-filled gorge at Goat Mountain (fig. 90). About 3 miles northeast of Cerro Castellan (Pl. II; H, 11), a post-Chisos Formation fault is covered by lava of the South Rim Formation. At many places the fault traces are covered by older gravel deposits. Most of the faults



, Punta de la Sierra.



FIG. 148. Looking southwest across the dipping strata on the flank of the Glenn Springs laccolith, toward Elephant Tusk.
A, Top of intrusive. B, Tilted Aguja beds. C, Javelina Formation. D, Black Peaks Formation. E, Chisos beds. F, Elephant Tusk. G, Backbone Ridge. H, Punta de la Sierra.



Fig. 149. Normal fault in soft Cretaceous rocks northeast of Maverick Mountain (Pl. II; O, 10). Aguja Formation on left, Javelina Formation on right; the vertical displacement is about 600 feet.

southwest of the highest Chisos Mountains form belts or groups. The faults in each belt appear to be related as they are subparallel and are downthrown in the same direction. The general trends in one group differ somewhat from the trends in adjacent groups and in some places are of different ages.

Punta de la Sierra fault belt.—The Punta de la Sierra fault belt (Pl. II; D–H, 11–15) includes normal faults that have broken the Chisos Formation into linear blocks, each stepped down toward the southwest. The Tule Mountain Trachyandesite caps most of the ridges, and the inter-ridge valleys are floored by the older gravel deposits. The escarpments are eroded, some are shifted a mile or more from the fault trace, and the lava-filled canyon at Goat Mountain is in one of the escarpments. The principal faults in this belt are contemporaneous with post-Chisos Formation (Upper Eocene) uplift in the central Chisos Mountains area.

Burro Mesa fault belt.—The Burro Mesa fault (Pl. II; H–Q, 12–14) is a normal fault downthrown toward the west, which extends along the eastern escarpment of Burro Mesa (fig. 150). The mesa, which now stands high above the surrounding area, is formed of Tertiary volcanic rocks that presumably cover the faulted southwestern end of the Chisos Pen anticline and flank the southeastern end of the Maverick Mountain anticline. Strata in both the upper Chisos Formation and the overlying South Rim Formation are synclinal and are strongly tilted by two intrusions (Pl. II, L, 12). Parts of the syncline and faults are covered by an ancient gravel deposit.

The Burro Mesa fault has about 3,000 feet of displacement near the crest of the Chisos Pen anticline (Pl. II; N, 12), where it drops Chisos beds against the Pen Formation. Near the southern end of Burro Mesa the fault bifurcates (Pl. II; K, 14). The eastern branch continues southeasterly



Fig. 150. The Burro Mesa fault line escarpment.
A, Approximate position of fault. B, Gulfian formations on upthrown side of fault. C, Tertiary volcanic rocks for fault line escarpment on downthrown side.

and the western branch trends more southerly, but both die out in the Chisos Formation on the northwest flank of Sierra Quemada dome (Pl. II; J, 14). The westernmost fault in the group cuts the Burro Mesa Riebeckite Rhyolite at the south end of Burro Mesa (Pl. II; K, 13) and passes northwestward beneath the old gravel deposited on top of the mesa. Southward it cuts the east end of Goat Mountain where the South Rim lavas are dropped to within about 800 feet of the base of the Chisos Formation.

The Burro Mesa fault belt is nearly parallel with the Punta de la Sierra fault belt, and, like it, most of its fault blocks are stepped down toward the west. The principal faults in the Burro Mesa group, however, cut the youngest member in the South Rim Formation, and the principal faults in the Punta de la Sierra belt were eroded prior to the deposition of that formation; thus the Burro Mesa group is younger.

Castolon—Terlingua Abaja fault belt.—From 3 miles southeast of Cerro Castellan (Pl. II; G, 10) northward to the Park boundary beyond Rattlesnake Mountain (Pl. II; L, 8) and northwestward to Terlingua Abaja (Pl. II; H, 6) is a group of northwest-trending normal faults that are downthrown toward the northeast (Pl. II; F–M, 6–10). These faults differ from the previous belts in the direction of throw. With the two other belts they outline a large compound graben west and southwest of the Chisos Mountains. They cut formations from the Burro Mesa Riebeckite Rhyolite downward through mid-Gulfian formations (fig. 151) and most of the faults in this group are probably the same age as those in the Burro Mesa fault belt (post-Oligocene). The lowest part of the compound graben is the multiple fault block east of Cerro Castellan; it begins near Bee Mountain and extends southeastward beyond Sierra de Chino. The floor of the lowest block is about 1,000 to 1,500 feet



FIG. 151. Fault in the Terlingua Abaja area. The front wheels of the truck are on the fault trace. Pen Formation on the left. The light rock, center, is Javelina Formation and the dark mass, upper right, is Alamo Creek Basalt Member of the Chisos Formation.



FIG. 152. Tilted clay and gravel beds about 2¼ miles northeast of Cerro Castellan.

structurally lower than Burro Mesa, which heretofore has been credited with being structurally the lowest area in the Sunken Block (Udden, 1907a, p. 81; Baker, 1935, p. 173). It is also in this area that the basin-fill deposits containing Miocene mammal bones have been found. The faults in this group are parallel to the Terlingua fault zone and most of them are downthrown in the same direction, but the fault scarps and fault-line escarpment of most of them seem older than the Terlingua fault scarp at the mouth of Santa Elena Canyon.

Post-Miocene deformation.—Bolson clay and indurated gravel deposits, some of which contain Miocene mammal bones, occur at several places in the Park (Pl. II). The valley fill deposits east of Cerro Castellan were previously mentioned (pp. 151–152). At one place, a mile southeast of Cerro Castellan (Pl. II; G, 10), the silty clay deposits lie against a fault cutting the Burro Mesa Riebeckite Rhyolite; at most places the beds are tilted up to angles of 20° to 35° and the dips are probably of structural origin (fig. 152). The largest area covered by bolsonlike deposits is east of the Chisos Mountains. Here most of the rocks have low dips that generally conform to the slope of the underlying surface, but along Estufa Canyon (Pl. II; M–N, 21–22) some of the conglomerate dips as steeply as 20°. East of Mariscal Mountain, indurated gravels lie against the eastern boundary fault of the Solis Graben (Pl. II; D–E, 22). In Mexico, about 8 miles south of Johnson's ranch (Pl. II; C, 14), a consolidated alluvial gravel seems to be against the Pen Formation.

SUMMARY

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In the preceding parts of this report, the available facts regarding land forms, sedimentary, volcanic, and intrusive igneous rocks, climate, fossils, and geologic structures have been set forth. This concluding chapter is a review of these facts and a summary of events that have led to the development of the geologic phenomena now preserved. Precambrian rocks are not exposed in the Big Bend, and Paleozoic rocks crop out only in isolated areas; most of this chapter deals with the rocks that were deposited, deformed, and eroded during the Mesozoic and Cenozoic Eras.

Paleozoic Era.—Paleozoic rocks crop out in the Marathon Basin and the Solitario north of the Park (p. 23). There are also a few thrust slices of Paleozoic rocks exposed in the Persimmon Gap—Dog Canyon area (pp. 23–28, and farther south pre-Cretaceous rocks crop out along the Sierra del Carmen escarpment in Mexico (pp. 4–5). In all these areas the Paleozoic rocks were highly deformed and eroded to a low rolling plain on which Cretaceous formations were deposited. Presumably, Paleozoic rocks similar to those exposed in the Marathon Basin underlie the Cretaceous formations in places other than the Persimmon Gap—Dog Canyon area, but they are not exposed and few wells have penetrated to depth sufficient to reveal their nature.

Mesozoic Era.—Mesozoic geosynclinal deposits are exposed along the Conchos River in northeastern Chihuahua, Mexico, and in the adjacent part of Trans-Pecos Texas. These include 4,000 feet of shale, thin limestone, and thick sandstone beds (with some gypsum) below and about 5,000 feet of massive, rudistid-bearing limestone above. In the foreland area, Coahuila Platform (Pl. XI), the basal deposits thin and successive parts of the lower sequence are absent because of overlap on the Paleozoic rocks. The basal part of the thick massive limestone (Glen Rose) of the Conchos River valley changes northeastward to alternating limestone and marl with basal conglomerate or conglomeratic sandstone in the Park. The Fredericksburg and Washita parts of the limestone sequence retain their massive character across the Big Bend country, and the Del Carmen and Santa Elena Limestones form imposing escarpments in Mesa de Anguila and the Sierra del Carmen. The Del Carmen Limestone extends far to the northeast as the Edwards Limestone, but toward the northwest in the central Diablo Plateau, the massive limestone changes into a marginal sandstone facies. The Santa Elena in the Park changes north-northeastward into a limestone and marl facies, and in the Fort Stockton area only thin tongues of the massive rudistid-bearing limestone interbedded with marl are present.

In the Park there was subaerial erosion at the end of the Comanchean; this erosion surface separates the Buda Limestone (uppermost Comanchean formation) from the overlying Boquillas Formation (Gulfian). Locally, there are small sinks in the Santa Elena and Buda Limestones, probably formed at this time. Pulsations that eventually caused the sea to withdraw at the end of Comanchean time probably began with the end of the Santa Elena Limestone deposition for there are marked changes in the thickness of the overlying Del Rio clay. In the southeastern Park area, the basal Del Rio clay is absent; presumably, the lower Del Rio sea did not cover that area and only the uppermost Del Rio clay, commonly less than 5 feet thick, separates the Santa Elena and Buda Limestones. Farther east in Terrell and Val Verde counties, the basal Del Rio clay is present, the top part of the formation is eroded, and locally in eastern Terrell County all the Del Rio is

absent. In these places the Buda lies directly on the Georgetown Limestone.

The basal Gulfian rocks in the Park, Boquillas Formation, are a sequence of marine argillaceous and chalky flagstone interbedded with marl. The basal part of the Boquillas Formation, Ernst Member, is Eagle Ford age. A section of Eagle Ford-age rocks, about 2,000 feet thick, crops out in the Sierra Vieja Mountains in northwestern Presidio County, but in the Park these rocks are only about 450 feet thick. In both areas the Eagle Ford-age rocks lie on the Buda Limestone, and throughout west Texas the hiatus between the Comanchean and Gulfian rocks represents all of Woodbine time. The top of the Boquillas Formation, San Vicente Member in the Park, is also a flagstone unit but it is of Austin age. The Boquillas Formation is overlain by the Pen Formation, a marine marl-clay unit. These rocks are beneath the marine sandstone and clay succession in the lower Aguja Formation. The upper Aguja is of continental origin and also consists of sand and clay. The Javelina, uppermost Gulfian formation, is dominantly bentonitic clay of continental origin.

An erosion surface separates the Ernst and San Vicente Members of the Boquillas Formation. In some places as much as 125 feet of Ernst Member was stripped before the San Vicente Member was deposited. The overlying Pen Formation seems to be conformable to the underlying San Vicente Member, but in some places post-Pen erosion removed as much as 400 feet of Pen beds before the overlying Aguja Formation was deposited. The contact between the marine and nonmarine parts of the Aguja Formation seems to be gradational, and similar conditions exist at the contact between the Aguja and Javelina Formations.

Sporadic volcanic activity first occurred in the Boquillas Formation where in some places thin, ashy clay layers are interbedded with the flagstone. Bentonitic clay layers are present in the Pen Formation, tuffaceous sandstone and clay occur at some places in the Aguja Formation, and the Javelina Formation is dominantly bentonitic clay. Tabular igneous bodies intruded the Pen and Aguja Formations on the west side of Mariscal Mountain and the Aguja Formation at the Cow Heaven anticline and Tortuga Mountain dome. These were probably emplaced during Late Cretaceous time and were folded concordantly in structures during the Laramide orogeny. Sills in the Boquillas crop out along the west side of the Sierra del Carmen and on Mesa de Anguila; they were probably also emplaced during Late Cretaceous time.

Asymmetric folds and thrust faults in the Santiago Mountains were formed during the Laramide orogeny. A fold-and-thrust-fault in Cretaceous rocks, exposed along the base of the Sierra del Carmen in Mexico, was formed at the same time. Farther west, a belt of post-Cretaceous deformation extends northwestward from Mariscal Mountain. The asymmetric anticline and thrust fault at Mariscal Mountain were formed during the Laramide orogeny. Other structures along this trend are the Cow Heaven anticline, Tortuga Mountain dome, the Basin syncline, Chisos Pen anticline, and the Christmas Mountains. Folds flanking this northwest-trending belt on the east are Sierra San Vicente, San Vicente anticline, and the Lone Mountain anticline; on the west is the Maverick Mountain anticline. A third belt of post-Cretaceous deformation is along the west-northwest side of the Park. Faults northeast of Mesa de Anguila, east of Lajitas, were formed before the Tertiary rocks were deposited, and the broad uplift forming the Terlingua monocline and some of the small thrust faults in that structure were formed during the Laramide orogeny.

Erosion following the formation of the post-Cretaceous folds and faults developed a ridge-and-basin surface where the structural belts remained high. The earliest Tertiary rocks were deposited in basins between the post-Cretaceous folds and/or fault blocks; as erosion and deposition progressed, the younger Tertiary forma-

tions overlapped the post-Cretaceous structures and finally buried all of them.

Cenozoic Era.—The earliest Tertiary rocks, Black Peaks Formation (Paleocene), were deposited on an eroded surface in the Javelina Formation (Gulfian) between the deformed belt in the Santiago Mountains on the east and the Mariscal to Christmas Mountains on the west. The source of sediments was local and probably was the Aguja and Javelina Formations exposed in the fold belt that extended northwestward from Mariscal Mountain. The Hannold Hill Formation (Lower Eocene) overlaps the Black Peaks and Javelina Formations toward the west. The chert and novaculite pebbles in the channel conglomerates probably came from erosion of the Paleozoic (Maravillas and Caballos Formations) rocks in Persimmon Gap. Uplift and erosion at the end of the Lower Eocene stripped the upper half of the Hannold Hill Formation from the north part of Tornillo Flat and resulted in angular relations between the Hannold Hill and overlying Canoe Formations. The sites of deposition for the Canoe (Middle Eocene) Formation extended still farther west and overlapped the older Tertiary formations; upper Canoe beds lie directly on middle Aguja Formation at the Tortuga Mountain dome, the Basin syncline, and the south end of the Lone Mountain anticline. The sills folded in the Gulfian formation on the west side of Mariscal Mountain, Cow Heaven anticline, and Tortuga Mountain were probably exposed and were the source of the igneous pebbles in the Canoe conglomerate. There seems to have been renewed uplift along the alignment extending northwestward from Mariscal Mountain at the end of the Middle Eocene. The Alamo Creek Basalt, basal member of the Chisos Formation (Upper Eocene), did not extend east of that northwest-trending alignment, and the Middle Eocene and Gulfian rocks uplifted along that alignment were not covered by Chisos Formation below a stratigraphic level about 500 feet above the Alamo Creek Basalt Member. At the north end of the Cow Heaven anticline, the Chisos Formation above the Alamo Creek Basalt lies directly on the Aguja Formation and on an eroded surface above 200 feet of upper Canoe Formation at Tortuga Mountain; similar relations were observed in the Basin syncline.

The Chisos Formation (Upper Eocene) was deposited during a time of repeated tilting, erosion, and deposition of clastic and pyroclastic rocks and lava flows. All of the lava members lie on eroded surfaces, and north of Sierra de Chino the Tule Mountain Member overlaps about 1,500 feet of older Chisos Formation. Erosion followed deposition of most of the lava member. The most conspicuous intraformational erosion surface is at Tule Mountain where the Bee Mountain Basalt Member is absent, and the Bee Mountain seems to have been the source of a boulder fanglomerate that fills a deep canyon. Some of the movements that occurred during deposition of the Chisos Formation are recorded in the Tertiary volcanic rock sequence flanking the Solitario. The small thrust faults (figs. 139, 140) suggest that the upward movements that later domed the area began as early as middle Upper Eocene.

Post-Upper Eocene uplift raised the Chisos Mountains and modified the belt of folded Cretaceous rocks that extends northwestward from Mariscal Mountain. The normal faults in the Punta de la Sierra fault belt, southwest of the Chisos Mountains, are of the same age. The normal fault along the east side of the Cow Heaven anticline and most of the normal faults at Mariscal Mountain, Sierra San Vicente, San Vicente anticline, Sierra del Carmen, and the faults flanking the post-Cretaceous asymmetric anticline in the Santiago Mountains were probably formed at the same time. The erosion that followed the post-Upper Eocene uplift reduced the Chisos Formation to about one-half its original thickness in the central Chisos Mountains and developed fault-line escarpments on most fault blocks toward the southwest. A canyon about 900 feet deep was cut across the fault block at Goat Mountain during this time, and about

3 miles farther southwest all of the Chisos Formation was removed. The post-Chisos Formation erosion surface is the most extensive unconformity preserved in the Tertiary rocks.

Extrusive activity during the Oligocene deposited the South Rim Formation. At most places in the central Chisos Mountains its basal lava units lie on middle Chisos Formation, but at one place in the Basin syncline middle South Rim Formation overlaps Chisos and Gulfian formations down to the Pen Formation. Northeast of Cerro Castellan the Burro Mesa Member, youngest lava in the South Rim Formation, lies on an eroded surface in the Javelina Formation.

Post-Oligocene intrusive activity further raised the central Chisos Mountains. The emplacement of the Chisos Mountains pluton was at this time and it further deformed the Cretaceous rocks that were first raised during the Laramide orogeny; the Chisos Formation was again domed and faulted by the post-Oligocene uplift, and the South Rim Formation was tilted and cut by intrusions. Several small intrusions in the southern Chisos Mountains are probably the same age. These are Sierra Quemada, Dominguez Mountain, Elephant Tusk, Backbone Ridge, and Hayes Ridge; two small plugs on Burro Mesa deformed both the Chisos and South Rim Formations. The normal faults in the Burro Mesa and Castolon—Terlingua Abaja fault belt are post-South Rim Formation and about the same age as the intrusions. Relations at the south end of the Burro Mesa fault and the intrusive dome at Sierra Quemada suggest that they are contemporaneous. It is the writer's belief that most of the faults in the Terlingua fault zone are of the same age and that they are correlative with the Chalk Draw —Muskhog Spring fault and faults in the McKinney Hills that extend southeastward into the western Sierra del Carmen. If this is correct, the boundary faults that outline the eastern and western sides of the Sunken Block are post-Oligocene.

The latest epoch of tilting and perhaps faulting is post-Miocene; it is recorded by deformed mammal bone-bearing silt beds in the fault block valley east and southeast of Cerro Castellan. It is likely that there was renewed movement along the Terlingua fault zone at this time which produced the youthful-appearing escarpment at the mouth of Santa Elena Canyon. The eastern boundary fault at the Solis Graben may cut a valley-fill conglomerate, terrace gravel deposits are faulted against the Pen Formation in Mexico south of Johnson's ranch, and high terrace gravel deposits east of the Chisos Mountains have been tilted.

The subsequent history in Big Bend National Park is dominantly that of erosion. Where the Rio Grande crosses folds and tilted fault blocks, such as Mariscal Mountain, Mesa de Anguila, and the Sierra del Carmen, it has carved deep, steep-walled canyons. The Rio Grande, and to a lesser extent Terlingua and Tornillo Creeks, has trenched the soft rocks in the intermontane basins. Large quantities of weak rocks have been removed from the Sunken Block leaving the hard rock masses standing in bold relief. Some of these are the Chisos Mountains, especially the pluton, Elephant Tusk, Backbone Ridge, Dominguez Mountain, Mule Ear Peak, Goat Mountain, Cerro Castellan, Maverick Mountain, and the Corazones Peaks. Weathering and erosion along joints have produced spectacular columns in many of the hard rock masses, erosion on alternating layers of hard and soft rocks has produced steplike topography, lava flows and massive limestone commonly cap high mesas, and most of the larger hard rock masses are surrounded by gravel-covered pediment slopes.

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